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Hydrologic Engineering Center

Application of the HEC-2 Bridge Routines

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This document assists the HEC-2 program user in preparing input for the bridge routines. An understanding of the basic program input requirements was assumed. The program computes the energy loss caused by structures such as bridges and culverts in two parts. One part consists of the losses that occur in reaches immediately upstream and downstream from the bridge where contraction and expansion of the flow is taking place. The second part consists of losses at the structure itself. As an alternative to having the program compute the losses, it is possible to input a loss (or water surface elevation) determined externally from the program. Appendices contain examples of three different types of computer runs. The HEC-2 User's Manual, available from the Hydrologic Engineering Center provides the input specifications for the program. User Manual editions singe August 1979 include this training document as an appendix.

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FOREWORD

This training document was written to assist users of computer program HEC-2, Water Surface Profiles, in calculating water surface profiles through bridges. Financial assistance for writing this document was provided by the Flood Plain Management Branch, Office of the Chief of Engineers. Computer program HEC-2 was written by Bill S. Eichert. Portions of previous HEC publications have been used in this training document.

The author wishes to acknowledge contributions by Mr. John C. Peters and Mr. Bill S. Eichert to the material contained in this document and for their reviews and comments.

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APPLICATION OF THE HEC-2 BRIDGE ROUTINES

by

Vernon R. Bonner*

INTRODUCTION

The purpose of this document is to assist the HEC-2 program user in preparing input for the bridge routines. An understanding of the basic program input requirements is assumed. General information on the program is provided in the "HEC-2 Water Surface Profiles - Users Manual" (reference f). This training document provides a review of the computational methods available in the program and guidelines on how to code the necessary data. Examples of input preparation are provided and the program solutions for the example problems are attached in the appendices. Suggested approaches for some typical bridge problems are also presented.

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METHODS AVAILABLE IN HEC-2

The program computes the energy loss caused by structures such as bridges and culverts in two parts. One part consists of the losses that occur in reaches immediately upstream and downstream from the bridge where contraction and expansion of the flow is taking place. The second part consists of losses at the structure itself. As an alternative to having the program compute the losses, it is possible to input a loss (or water surface elevation) determined externally from the program.

Contraction & Expansion Losses

Losses due to contraction and expansion of flow between cross sections are determined by standard step profile calculations. Manning's equation is used to calculate friction losses, and all other losses are described in terms of a coefficient times the absolute value of the change in velocity head between adjacent cross sections. When the velocity head increases in the downstream direction, a contraction coefficient is used; and when the velocity head decreases, an expansion coefficient is used.

The second part of the loss calculation, for losses that occur at the structure itself, is made by either the normal bridge routine or the special bridge routine.

Normal Bridge Routine

The normal bridge routine handles a bridge cross section in the same manner as a natural river cross section, except that the area of the

bridge below the water surface is subtracted from the total area, and the wetted perimeter is increased where the water is in contact with the bridge structure. The bridge deck is described either by entering the constant elevations of the top of roadway and low chord as variables ELTRD and ELLC respectively on card X2, or by specifying a table of roadway stations and elevations, and corresponding low chord elevations, on BT cards. When only ELLC and ELTRD are used, these elevations are extended horizontally until they intersect the ground line defined on GR cards. Pier losses are accounted for by the loss of area and the increased wetted perimeter of the piers as described in terms of cross section coordinates, usually on the GR card.

Special Bridge Routine

The special bridge routine computes losses through the structure for either low flow, pressure flow, weir flow, or for a combination of these. The profile through the bridge is calculated using hydraulic formulas to determine the change in energy and water surface elevation through the bridge.

Low Flow. The procedure used for low flow calculations in the special bridge routine depends on whether the bridge has piers. Without piers, the low flow solution is accomplished by standard step calculations in the normal bridge routine. The transfer to the normal bridge routine is necessary because the equations used in the special bridge routine for low flow are based on the obstruction width due to the piers.

Without piers, the special bridge solution would indicate that no losses would occur. For a bridge with piers, the program goes through a momentum balance for cross sections just outside and inside the bridge to determine the class of flow. The momentum calculations are handled by employing the following momentum relations based on the equations proposed by Koch and Carstanjen (references b and c).

$$m_1 - m_{p1} + \frac{Q^2}{g(A_1)^2}\left(A_1 - \frac{C_D}{2}A_{p1}\right) = m_2 + \frac{Q^2}{gA_2} = m_3 - m_{p3} + \frac{Q^2}{gA_3}$$

where,

m_1, m_2, m_3 = $A_1\bar{y}_1$, $A_2\bar{y}_2$ and $A_3\bar{y}_3$, respectively

m_{p1}, m_{p3} = $A_{p1}\bar{y}_{p1}$ and $A_{p3}\bar{y}_{p3}$, respectively

A_1, A_3 = unobstructed (gross) area at upstream and downstream sections, respectively

A_2 = flow area (gross area - area of piers) at a section within constricted reach

A_{p1}, A_{p3} = obstructed areas at upstream and downstream sections, respectively

$\bar{y}_1$, $\bar{y}_2$, $\bar{y}_3$ = vertical distance from water surface to center of gravity of A_1, A_2, A_3, respectively

C_D = drag coefficient equal to 2 for square pier ends and 1.33 for piers with semicircular ends.

$\bar{y}_{p1}$, $\bar{y}_{p2}$ = vertical distance from water surface to center of gravity of A_{p1} and A_{p3}, respectively

Q = discharge

g = gravitational acceleration

The three parts of the momentum equation represent the total momentum flux in the constriction expressed in terms of the channel properties and flow depths upstream, within and downstream of the constricted section. If each part of this equation is plotted as a function of the water depth, three curves are obtained (Figure 1) representing the total momentum flux in the constriction for various depths at each location. The desired solutions (water depths) are then readily available for any class of flow. The momentum equation is based on a trapezoidal section and therefore requires a trapezoidal approximation of the bridge opening. A logic diagram for the momentum calculation is shown in Figure 2.

Class A low flow occurs when the water surface through the bridge is above critical depth, i.e., subcritical flow. The bridge routine uses the Yarnell equation for this class of flow to determine the change in water surface elevation through the bridge. As in the momentum calculations, a trapezoidal approximation of the bridge opening is used to determine the areas.

$$H_3 = 2K\,(K + 10\omega - 0.6)\,(\alpha + 15\alpha^4)\,V_3^2/2g$$ where,

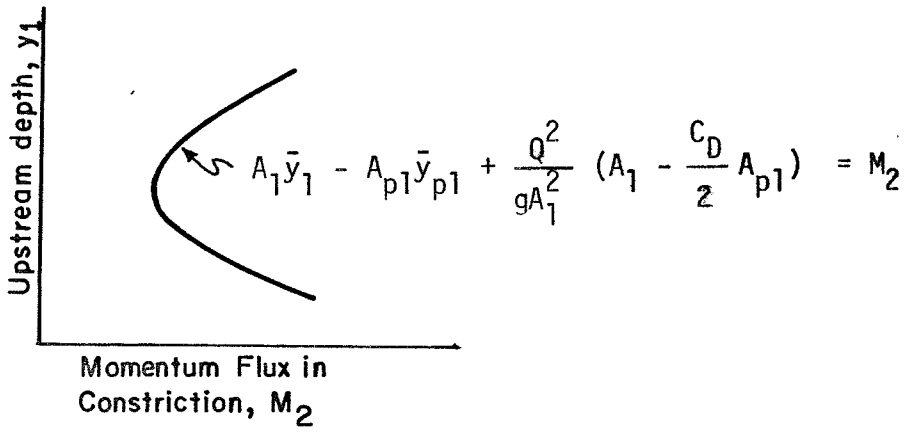
H_3 = drop in water surface in feet from upstream to downstream sides of the bridge

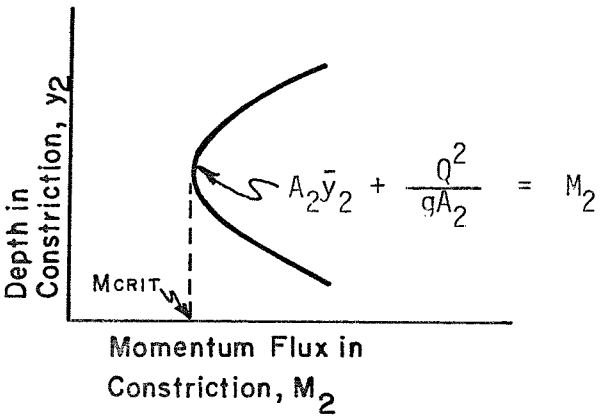
K = pier shape coefficient

ω = ratio of velocity head to depth downstream from the bridge

$\alpha = \dfrac{\text{obstructed area}}{\text{total unobstructed area}}$

V_3 = velocity downstream from the bridge in feet per second





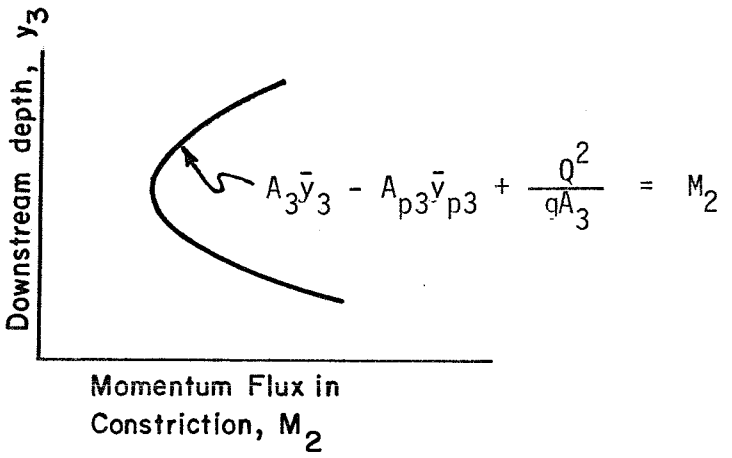
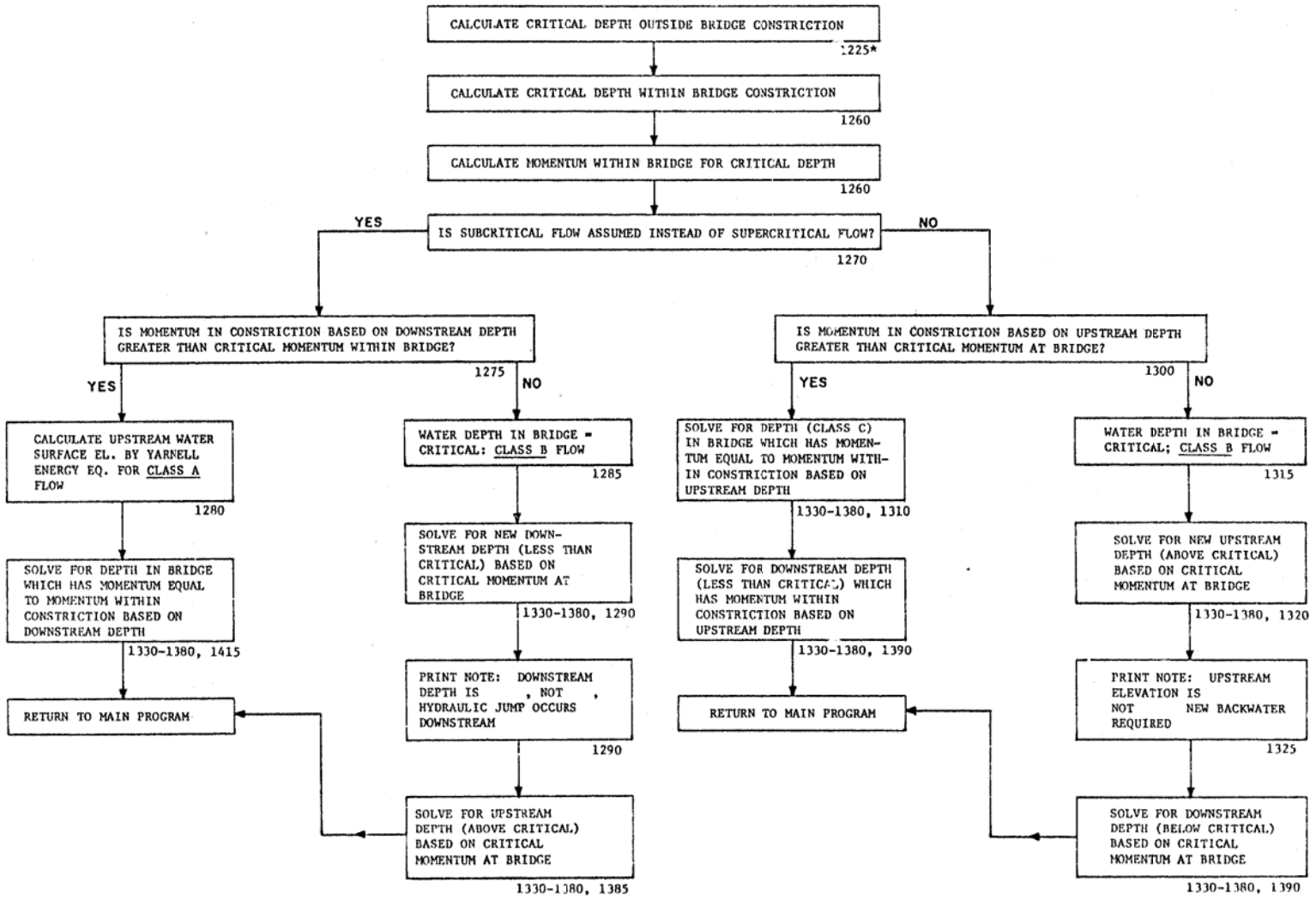


Figure 1. Momentum Curves from Special Bridge Method

SUBPROGRAM BLFLO, LOW FLOW CONTROL



*Numbers refer to statement numbers in source deck of computer program

Figure 2

The computed upstream water surface elevation is simply the downstream water surface elevation plus H_3. With the upstream water surface elevation known, the program computes the corresponding velocity head and energy elevation for the upstream section.

Class B low flow can exist for either a subcritical or supercritical profile. For either profile, class B low flow occurs when the profile passes through critical depth in the bridge constriction. For a subcritical profile, critical depth is determined in the bridge, a new downstream depth (below critical) and the upstream depth (above critical) are calculated by finding the depths whose corresponding momentum fluxes equal the momentum flux in the bridge for critical depth. With this solution, Statement 5227 DOWNSTREAM ELEV IS X, NOT Y, HYDRAULIC JUMP OCCURS DOWNSTREAM is printed with the elevation X as the supercritical elevation. The program does not provide the location of the hydraulic jump. A supercritical profile could be computed starting at the downstream section with a water surface elevation X. For a supercritical profile, the bridge is acting as a control and is causing the upstream water surface elevation to be above critical depth. Momentum equations are again used to recompute an upstream water surface elevation (above critical) and a downstream elevation below critical depth. For this situation, the Statement 5920 UPSTREAM ELEVATION IS X NOT Y, NEW BACKWATER REQUIRED is printed indicating a subcritical profile should be calculated upstream from the bridge starting at elevation X.

Class C low flow is computed for a supercritical profile where the water surface profile stays supercritical through the bridge con-

striction. The downstream depth and the depth in the bridge are computed by the momentum equations based on the momentum flux in the constriction and the upstream depth.

Pressure Flow. The pressure flow computations use the orifice flow equation of U. S. Army Engineering Manual 1110-2-1602, "Hydraulic Design of Reservoir Outlet Structures," August 1963 (reference h):

$$Q = A\sqrt{\frac{2gH}{K}} \qquad \text{where,}$$

H = difference between the energy gradient elevation upstream and tailwater elevation downstream

K = total loss coefficient

A = net area of the orifice

g = gravitional acceleration

Q = total orifice flow

The total loss coefficient K, for determining losses between the cross sections immediately upstream and downstream from the bridge, is equal to 1.0 plus the sum of loss coefficients for intake, intermediate piers, friction, and other minor losses. The section on Loss Coefficients provides values for the total loss coefficient and shows the derivation of the equation and the definition of the loss coefficient.

Weir Flow. Flow over the bridge and the roadway approaching the bridge is calculated using the standard weir equation:

$$Q = CLH^{3/2} \qquad \text{where,}$$

C = coefficient of discharge

L = effective length of weir controlling flow

H = difference between the energy grade line elevation and the roadway crest elevation

Q = total flow over the weir

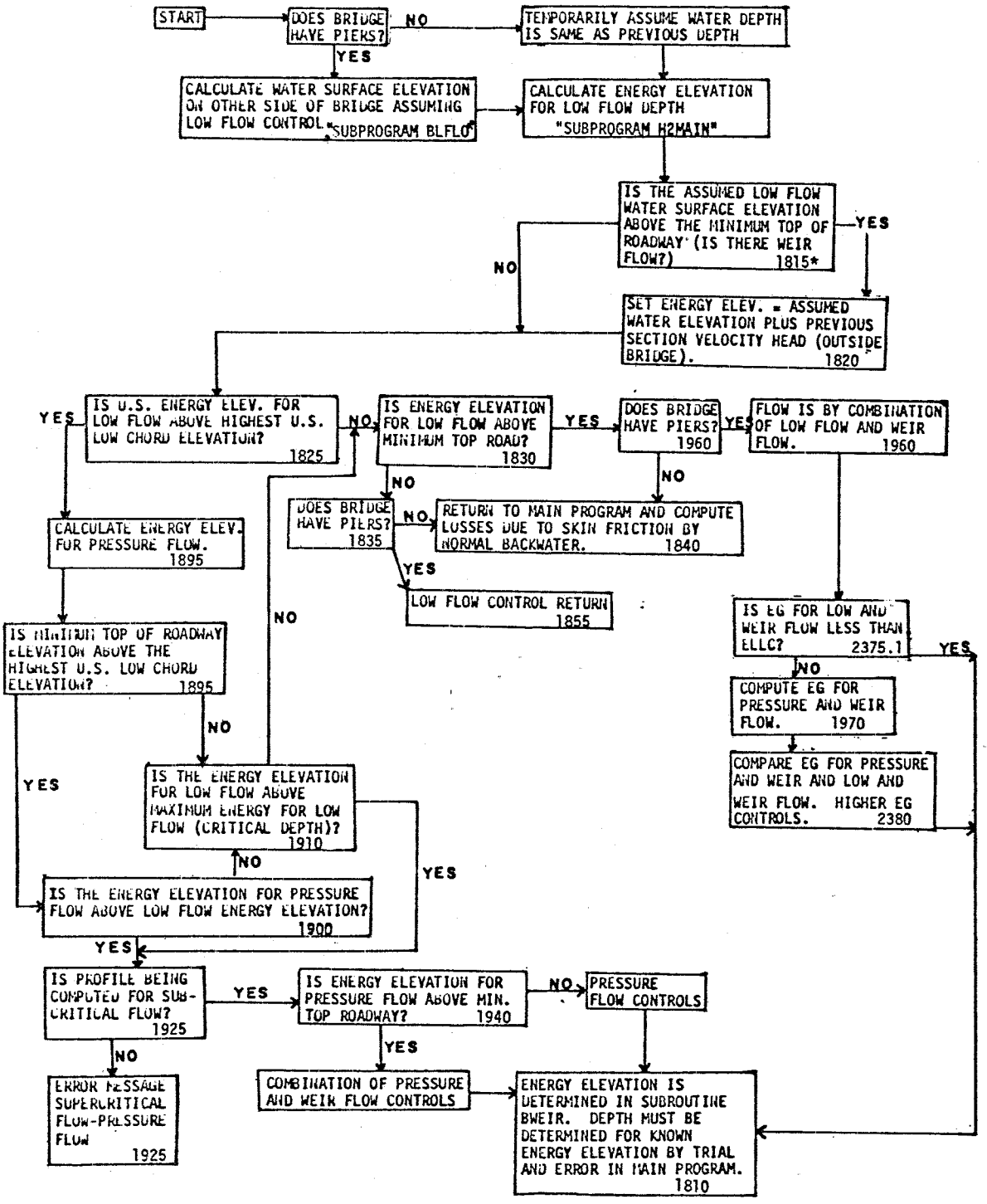
The approach velocity is included by using the energy grade line elevation in lieu of the upstream water surface elevation for computing the head, H. Values for the coefficient of discharge "C" are presented in the section on Loss Coefficients. Where submergence by tailwater exists, the coefficient "C" is reduced by the program according to the method indicated in reference i. Submergence corrections are based on an ogee spillway shape. As shown in Water Surface Profiles, I.H.D. Vol 6 (reference 1) the correction for submergence based on an ogee section can lead to errors for high submergence on weirs with other shapes. A total weir flow, Q, is computed by subdividing the weir crest into segments, computing L, H, a submergence correction and Q for each segment, and summing the incremental discharges.

Combination Flow. Sometimes combinations of low flow or pressure flow occur with weir flow. In these cases a trial and error procedure is used, with the equations just described, to determine the amount of each type of flow. The procedure consists of assuming energy elevations and computing the total discharge until the computed discharge equals, within one percent, the discharge desired.

Decision Logic. The general flow diagram for the special bridge routine is shown in Figure 3. By following the decision logic associated with a bridge solution, the program user can determine what adjustments he could make in the program input to alter the computed solution.

GENERAL FLOW DIAGRAM

SPECIAL BRIDGE METHOD



*Numbers refer to statement numbers in subprogram BWEIR.

Figure 3

A discussion of the logic sequence is provided to assist the user in interpreting the solutions he obtains.

The first step in the special bridge routine is to assume low flow conditions and estimate the water surface elevation on the other side of the bridge. How that estimate is made depends on whether the bridge has piers. If there are bridge piers, the program goes through the momentum equations to determine class of flow and water surface elevation. Without piers, the program temporarily assumes the water depth is the same on both sides of the bridge.

The program then checks for weir flow by comparing the estimated water surface elevation to the minimum top of road elevation (ELTRD). If it is possible that weir flow exists, the program estimates an energy elevation based on the velocity head at the previous section.

The program then compares the estimated low flow energy elevation to the maximum elevation of the bridge low chord (ELLC). If the low flow energy elevation (EGLWC) is greater than the low chord elevation (ELLC) the program will calculate an energy elevation assuming pressure flow (EGPRS). If the low flow energy elevation is less than ELLC, the program concludes that low flow controls and checks again to determine if weir flow exists. If there is weir flow, the program will check for piers. With piers, a trial and error solution will be made for low flow (by the Yarnell equation) and weir flow (by the weir equation). Without piers, the normal bridge solution (standard step calculation with adjustments in area and wetted perimeter) will be used to compute the

upstream elevation. If weir flow did not exist, the program would check for piers and then solve for a low flow solution. With piers, the low flow solution would be based on the momentum or the Yarnell equation; and without piers, the solution would be computed using standard step calculations.

Had the energy elevation required for pressure flow (EGPRS) been calculated, the program would go on to compare the low flow energy elevation EGLWC with EGPRS to see which controls. The higher of the two controls, as illustrated in the Typical Discharge Rating Curve shown in Figure 4.

One exception to the direct comparisions of the two energy elevations is when the minimum elevation of the top of road (ELTRD) is less than the maximum elevation of the low chord (ELLC). For this type of bridge, a combination of weir flow and low flow can occur. The low flow energy elevation (EGLWC) is compared to the estimated maximum energy elevation for low flow control (1.5 times depth plus invert elevation), rather than EGPRS, because the low road elevation would cause weir flow to exist prior to the occurrence of pressure flow. Depth is defined here as the difference between the low chord (ELLC) and the invert elevation (ELMIN).

At critical depth, 1.5 times the depth represents the minimum specific energy that could occur for a rectangular section. If critical depth occurred just at the maximum low chord elevation, it would produce the maximum possible energy elevation for low flow. Therefore, an energy elevation greater than that value would have to be for pressure flow. For the energy range between the low chord and the maximum low flow energy,

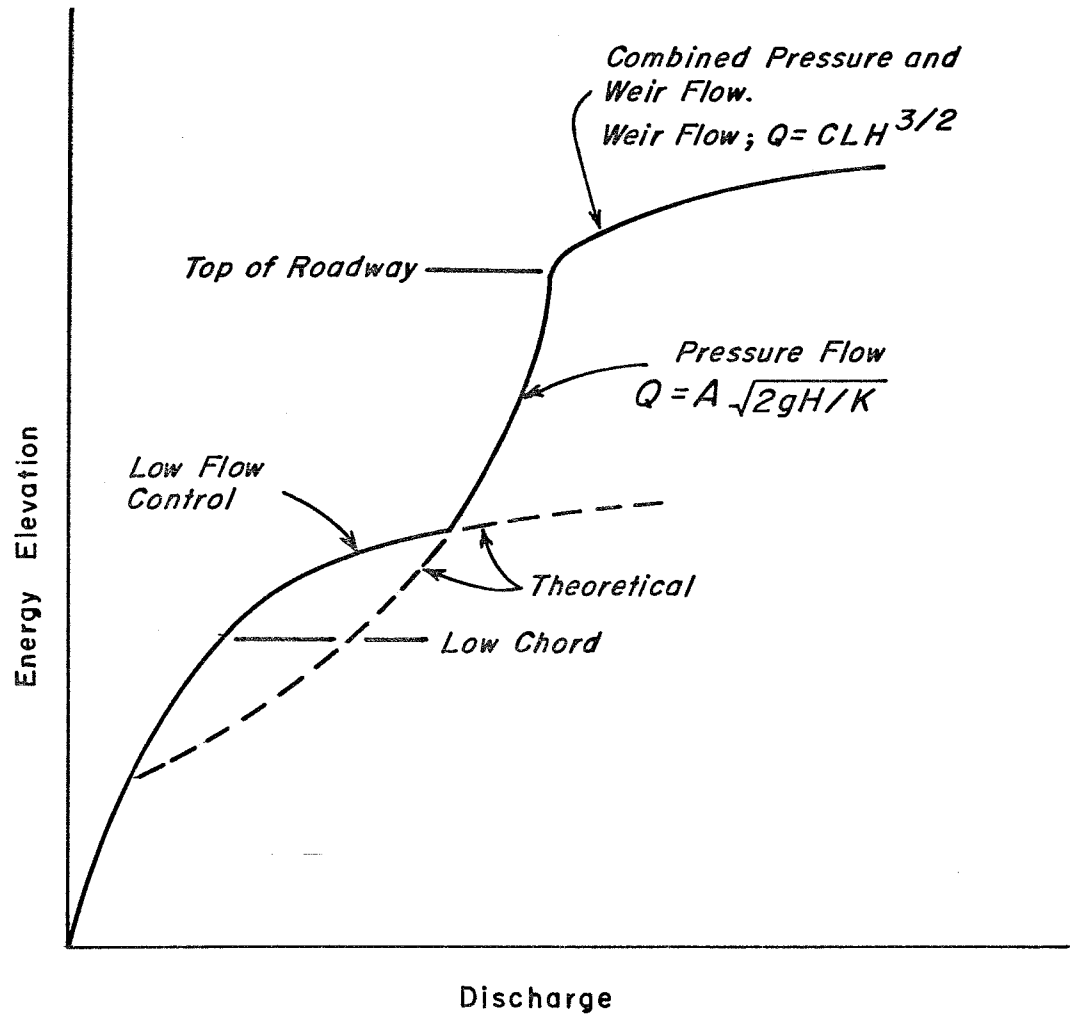


Figure 4. Typical Discharge Rating Curve for Bridge Culvert

the program will compute the energy elevations for low and weir flow and pressure and weir flow. The higher of the two energy elevations will control. Energy elevations below the maximum low chord are for low flow or low and weir flow for this type of bridge.

Based on the previous checks, the bridge routine has differentiated between low flow and pressure flow. With either type of flow, the program checks against the minimum top of road elevation (ELTRD) to determine if weir flow also exists. If the energy elevation is greater than ELTRD, a trial and error solution is made to determine the distribution of flow. The computed weir flow is listed under QWEIR and the flow under the bridge is given under QPR regardless of whether it is low flow or pressure flow. The flow diagram for computing the combination flow solution is shown in Figure 5. Up to 20 iterations are made to balance the total discharge to within 1% of the given discharge.

Important parameters in the decision logic of the special bridge routine are the two test elevations ELLC and ELTRD. Because they play such an important role in the bridge routine, it is recommended they always be coded as input on fields 4 and 5 of the X2 card.

Input Losses. One other method of computing water surface profiles through bridges is to input the bridge loss. The loss used could be just the "structure" loss, or it could be the total loss between any two adjacent cross section. Differences in water surface elevations can be read on the X5 card for each discharge profile. The field read on the X5 card is called by variable INQ on the second field of the J1 card.

SUBPROGRAM BWEIR, COMBINATION OF WEIR FLOW AND ORIFICE (OR LOW) FLOW

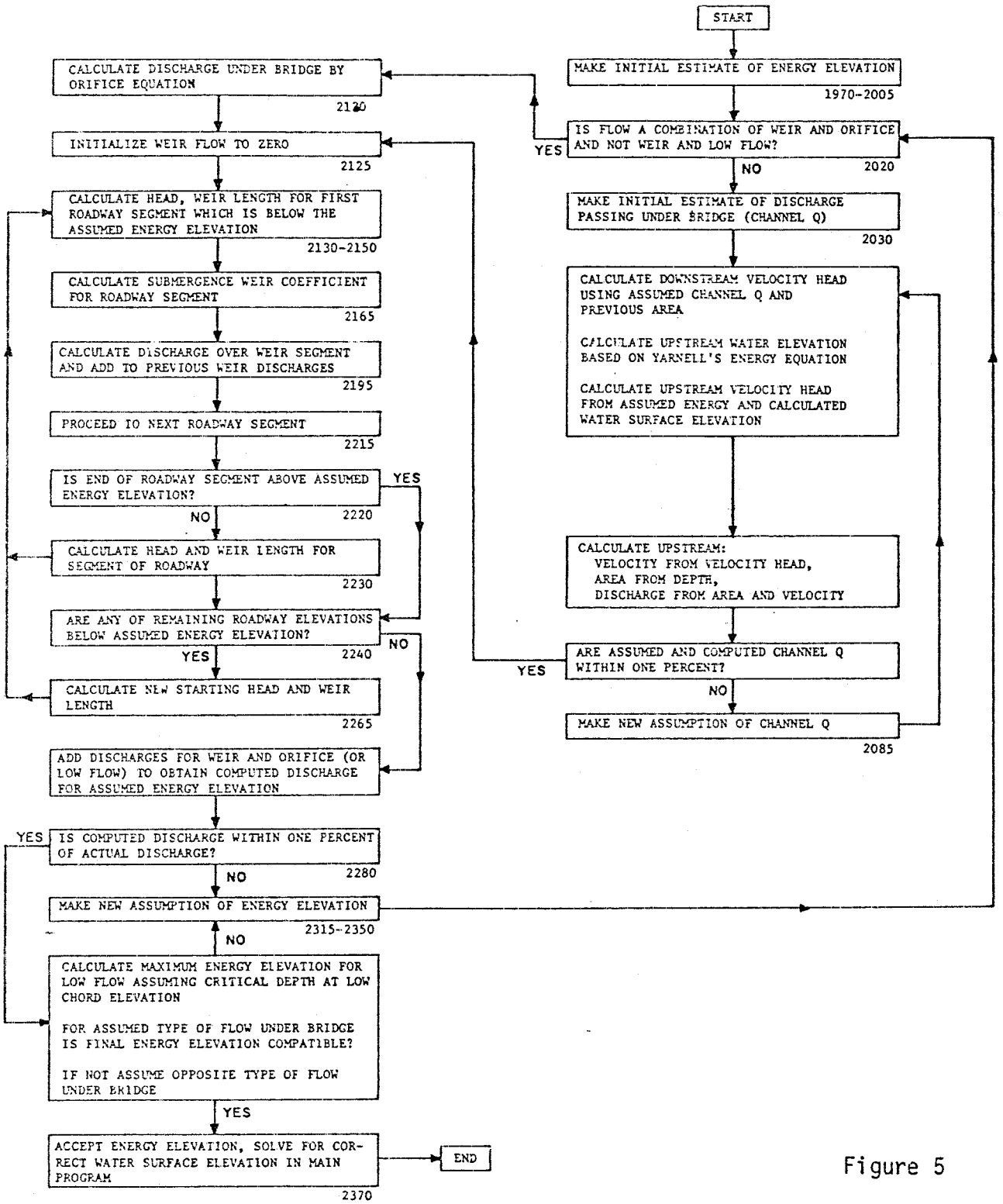


Figure 5

For control structures, the known water surface elevations as provided by a rating curve can be read on an X5 card for multiple profiles. However, for a given X5 card, the data must consist entirely of either known water surface elevations or of differences in water surface elevation. Both types of input cannot be placed on the same card.

GENERAL MODELING GUIDELINES

Considerations in modeling the geometry of a reach of river in the vicinity of a bridge are essentially the same for both the normal and special bridge routine. Suggested techniques are presented in this section and are applied in subsequent examples on bridge coding.

Cross Section Locations

Figure 6 shows in plan view the basic configuration of cross sections for computing losses through bridges. For ease of discussion, assume a subcritical profile starting downstream from the bridge.

Section 1 is sufficiently downstream from the bridge that flow is not affected by the bridge. The flow has fully expanded, and the basic input problem is to determine how far downstream from the bridge the cross section should be located. A rule of thumb is to locate the downstream section about four (4) times the average length of the side constriction caused by the bridge abutments. Therefore, section 1 would be located downstream from the bridge 4 times the distance AB or CD shown in Fig. 6. Because the constriction of flow may vary with the discharge, the downstream reach length should represent the average condition if a range of discharges are used in the model.

Locating cross section 1 based on a 4:1 expansion of flow downstream from the bridge may provide a reach length to cross section 2 that is too long for a reasonable estimate of friction loss. If in-

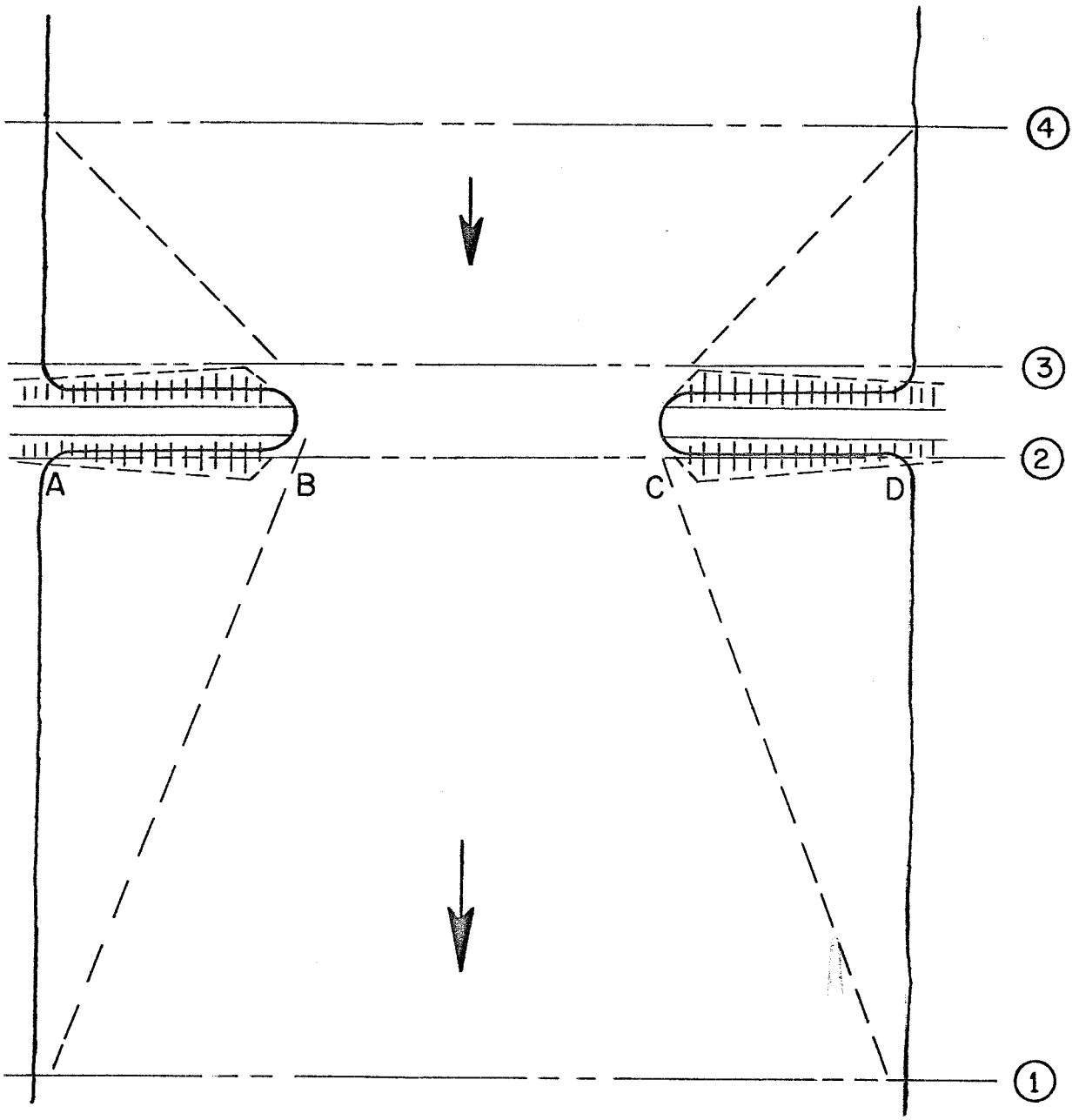


Figure 6. Cross Section Locations in the Vicinity of Bridges

termediate cross sections are required, the 4:1 expansion rate could be used to locate the lateral extent of intermediate sections. The user should carefully review the program output to determine if an adequate number of cross sections are used. A change in energy slope by a factor of two between the two sections and a relatively long reach would indicate a need for intermediate sections.

Section 2 is a river cross section immediately (i.e., within a foot or two) downstream from the bridge. The section should represent the effective* flow area just outside the bridge and its location could be considered as the downstream face of the bridge. It is important to work with effective flow area because it is assumed in the application of the energy equation that the mean downstream velocity for each subsection can be determined from Manning's equation. The method used to define the effective flow area at this cross section is discussed under Effective Flow Area. The standard step solution at section 2 would include determination of the expansion loss from section 2 to section 1.

The bridge loss occuring from section 2 to section 3 is determined by either the special bridge routine with the SB card or by standard step calculations through one or two sections that define the bridge opening (normal bridge routine). The selection of the bridge routine

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*Effective flow is that portion of flow where the main velocity is normal to the cross section and in the downstream direction.

and the input requirements are presented in subsequent sections.

Section 3 represents the effective flow area just upstream from the bridge. The reach lengths from section 2 to section 3 are generally equal to the width of the bridge. The energy elevation computed by the special bridge routine is applied to this section or, for the normal bridge routine, a standard step solution from a section in the bridge to this section provides the energy elevation. The energy loss computed between sections 2 and 3 represents the loss through the bridge structure itself.

Section 4 is an upstream section where the flow lines are approximately parallel and the full cross section is effective. Because the flow contraction can occur over a shorter distance than the flow expansion, the reach length between sections 3 and 4 can be about one (1) times the average bridge opening between the abutments (distance B-C in Figure 6). However, this criterion for locating the upstream section may result in too short a reach length for situations where the ratio of the width of the bridge opening to the width of the flood plain is small. An alternative criterion would be to locate the upstream cross section a distance equal to the bridge contraction (distance AB or CD in Figure 6). The program will compute the contraction portion of the bridge loss over this reach length by the standard step calculations.

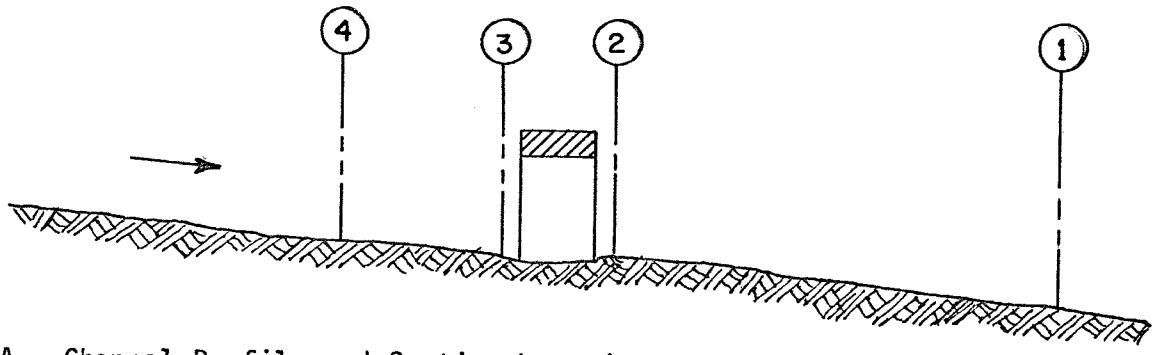
Effective Flow Area

A basic problem in setting up the bridge routines is the definition of effective flow area near the bridge structure. Referring to

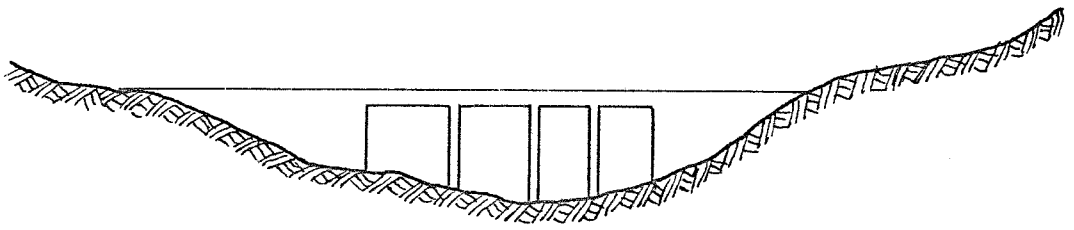
Figure 6, the dashed lines represent the effective flow boundary for low flow and pressure flow conditions. Therefore, for cross sections 2 and 3, ineffective flow areas to either side of the bridge opening (along distance AB and CD) should not be included for low flow or pressure flow. The elimination of the ineffective overbank areas can be accomplished by redefining the geometry at sections 2 and 3 (as shown in part C of Figure 7) or by using the natural ground profile and requesting the program's effective area option to eliminate the use of the overbank area. By redefining the cross section, a fixed boundary is used at the sides of the cross section to contain the flow, when in fact a solid boundary is not physically there. The use of the effective area option does not add wetted perimeter to the flow boundary above the given ground profile.

The bridge example shown in Figure 7 is a typical situation where the bridge spans the entire floodway and its abutments obstruct the natural floodway. This is the same situation as was shown in plan view in Figure 6. The section numbers and locations are the same as those discussed in Cross Section Locations. The input problem is to convert the natural ground profile at cross sections 2 and 3 from the section shown in part "b" to that shown in part "c" of Figure 7.

The effective area option of the program (IEARA = 10 in field 1 of the X3 card) is used to keep all the flow in the channel until the elevations associated with the left and/or right bank stations are exceeded by the computed water surface elevation. The program will allow the controlling elevations of the left and right bank stations to be



A. Channel Profile and Section Locations



B. Bridge Cross Section on Natural Floodway

C. Portion of Cross Sections 2 & 3 Effective for Low Flow and Pressure Flow

Figure 7. Cross Sections Near Bridges

specified by the user. This is done by reading in effective-area elevations (ELLEA and ELREA) in fields 8 and 9 of the X3 card. If these elevations are not read in, elevations specified on GR cards for the left and right bank stations will be used.

The effective area option applies to the left and right bank stations; therefore, those stations should coincide with the abutments of the bridge. For cross sections 2 and 3, the left and right bank stations should line up with the bridge abutments. An X3 card would be used with these sections to call for the effective area option and to designate effective-area elevations for the left and right bank stations. The given elevations would correspond to an elevation where weir flow would just start over the bridge. For the downstream section, the threshold water surface elevation for weir flow is not usually known on the initial run, so an estimate must be made. An elevation anywhere between the low chord and top-of-road elevation could be used; so an average of the two elevations might be a reasonable estimate.

Using the effective area option to define the effective flow area allows the entire overbank to become effective as soon as the effective-area elevations are exceeded. The assumption is that under weir flow conditions, the water can generally flow across the whole bridge length and the entire overbank in the vicinity of the bridge would be effectively carrying flow up to and over the bridge. If it is more reasonable to assume only part of the overbank is effective for carrying flow when the bridge is under weir flow, then the cross section should be redefined

for sections 2 and 3 to eliminate the portion of the overbank area considered ineffective even under weir flow conditions.

Cross section 3, just upstream from the bridge, is usually coded in the same manner as section 2. In many cases the cross sections are identical. The only difference generally is the elevation to use for the effective area option. For the upstream section, the elevation would be the low point of the top-of-road (ELTRD).

Using the effective area option in the manner just described for the two sections on either side of the bridge provides for a constricted section when all of the flow is going under the bridge. When the water surface is higher than the control elevations used, the entire cross section is used. The program user should check the computed solutions on either side of the bridge section to insure they are consistent with the type of flow. That is, for low flow or pressure flow solutions, the printout should show the effective area restricted to the main channel. When the bridge routine indicates weir flow, the solution should show that the entire cross section is effective.

Selection of Methods

When selecting the method of computing the water surface profile through a bridge, there are three basic choices: (1) determine the change in water surface elevation or the water surface elevation by an "external" technique and input the results into the program, (2) cal-

culate the energy loss based on friction using the standard step method - normal bridge routine, or (3) calculate the energy loss by previously discussed formulas of the special bridge routine. Each method should be considered and the following discussion provides some basic guidelines.

Input Losses. The following are examples of when a change or known water surface elevation might be read into the program:

1. If a structure is a control and a rating curve is available, reading in the known water surface elevation is the easiest and surest way to establish proper water surface elevations.

2. The use of observed data to estimate losses through a bridge can also be an expeditious method of establishing the losses.

3. An alternate computation technique can be used such as the Bureau of Public Roads procedure (reference j) for determining the loss for low flow conditions. The calculated loss can then be read in. Care must be taken to insure the loss calculated by alternate methods are properly used in the program. For example, the Bureau's technique provides the increase in water surface elevation above the normal water surface elevation without the bridge. Therefore, it includes the effects of contraction and expansion losses and the loss caused by the structure, but it does not reflect the normal friction loss that would occur without the bridge.

Normal Bridge Routine. The use of the standard step method for computing losses is most applicable when friction losses are the predominate consideration. The following examples are some typical cases

where the normal bridge routine might be used.

1. Because the special bridge routine requires a trapezoidal approximation of the bridge opening for low flow solutions, the normal bridge routine could be used where the flow area cannot be reasonably approximated by a trapezoid. (See the suggested approach for Multiple Bridge Openings.)

2. For long culverts under low flow conditions, the standard step method is the most suitable approach. Several sections can be taken through the culvert to model changes in grade or shape, or to model a very long culvert.

3. In cases where the bridge and abutments are a small obstruction to the flow, the normal bridge routine can be used.

4. In the special bridge routine, the correction for submergence in the weir flow calculations is not very reliable for high submergence on weirs that are not ogee shaped. The normal bridge routine may then be preferable.

Special Bridge Routine. The special bridge routine is capable of solving a wide range of flow problems. The following are situations where the routine is applicable.

1. The special bridge routine will determine the class of low flow based on a trapezoidal approximation of a bridge with piers. If a bridge opening can be reasonably modeled by a trapezoid, the program will determine when the profile goes through critical depth and what the corresponding water surface elevation is on either side of the bridge.

2. Pressure flow is computed using the orifice equation. The ori-

fice coefficient can be computed to account for friction; therefore, the special bridge routine would be suitable for pressure flow through long culverts.

3. Weir flow is computed in the special bridge routine; therefore, dams and weirs can be modeled as well as bridges. When computing pressure flow or weir flow, the program user might consider whether the bridge deck could survive such conditions.

4. Combinations of low or pressure flow and weir flow can be computed using the hydraulic formulas. An iterative procedure solves the combination flow problem for a variety of conditions. For low flow and weir flow solutions the bridge must have piers for the program to handle the low flow part of the combination flow. Otherwise the program will revert to the normal bridge routine.

Loss Coefficients

After the cross sections are located and the method of solution is determined, the program user has to select coefficients associated with the method chosen. For the normal bridge routine the Manning's "n" values are used to determine the friction loss. The contraction and expansion losses caused by the bridge are estimated using contraction and expansion coefficients.

Contraction and Expansion Coefficients. These coefficients are used to compute energy losses associated with changes in the shape of river cross sections. The loss due to expansion of flow is usually

much larger than the contraction loss, and losses from short abrupt transitions are larger than losses from gradual transitions. The transition loss is computed by multiplying a coefficient times the absolute difference in velocity heads between cross sections. If the values for the coefficients are being redefined to account for contraction and expansion through a bridge, the new values are read on the NC card prior to the section where the change in velocity head is evaluated. Referring back to Figure 6, on a subcritical profile the new values should be read in just before section 2 and changed back to the original values after section 4. Typical values are shown below.

	Coefficients	
	Expansion	Contraction
No transition loss computed	0.0	0.0
Gradual transitions	0.3	0.1
Bridge sections	0.5	0.3
Abrupt transitions	0.8	0.6

The maximum value for the expansion coefficient would be one (1.0).

Special Bridge Coefficients. When using the special bridge routine, coefficients must be read in for the Yarnell equation, the orifice equation, and the weir equation. The following discussion provides suggested values and methods for estimating the required coefficients.

Pier Shape Coefficient XK is used in Yarnell's energy equation for computing the change in water surface elevation through a bridge for

class A low flow. Because the calculation is based on the presence of piers, both the coefficient and a total width (BWP) must be read on the SB card. If there are no piers, both variables can be left blank and the program will use a standard step solution for low flows. The following table gives values of XK for various pier shapes.

Pier Shape	K
Semicircular nose and tail	0.90
Twin-cylinder piers with connecting diaphragm	0.95
Twin-cylinder piers without diaphragm	1.05
90° triangular nose and tail	1.05
Square nose and tail	1.25

The Yarnell equation is a semi-empirical equation based on hydraulic model data. As such, it probably should not be applied in cases where the flow obstruction is something other than a pier; for example, the fill separating twin circular culverts.

Loss Coefficient XKOR is used in the orifice flow equation, $Q = A\sqrt{2gH/K}$. This form of the equation can be derived by applying the energy equation from a point just downstream from the bridge (2) to a point just upstream (1).

$$y_1 + Z_1 + \alpha_1 \frac{V_1^2}{2g} = y_2 + Z_2 + \alpha_2 \frac{V_2^2}{2g} + H_L \qquad (1)$$

where:

y = depth of water

Z = invert elevation

$\alpha \frac{V_2^2}{2g}$ = velocity head

H_L = head loss

Defining the head (H) on the orifice as the difference between the upstream energy elevation and the downstream water surface elevation (the definition used in HEC-2) produces:

$$H = (y_1 + Z_1 + \frac{\alpha_1 V_1^2}{2g}) - (y_2 + Z_2) \quad (2)$$

Substituting H from equation 2 into equation 1 produces:

$$H = \frac{\alpha_2 V_2^2}{2g} + H_L \quad (3)$$

Head loss (H_L) through the bridge can be defined in terms of the bridge velocity head and loss coefficient K_b. The expansion to a point just downstream can be defined by an expansion coefficient K_e and the change in velocity head.

$$H_L = K_b \frac{V_b^2}{2g} + K_e \left(\frac{V_b^2}{2g} - \frac{\alpha_2 V_2^2}{2g} \right) \quad (4)$$

where:

b = subscript designating the bridge

The head loss equation 4 then can be used to define H_L in equation 3:

$$H = \frac{\alpha_2 V_2^2}{2g} + K_b \left(\frac{V_b^2}{2g} \right) + K_e \left(\frac{V_b^2}{2g} - \frac{\alpha_2 V_2^2}{2g} \right) \quad (5)$$

If the expansion coefficient (K_e) is taken as 1.0, the equation can be rewritten into the form of the orifice equation by adding the continuity equation ($Q = VA$).

$$Q = A\sqrt{2gH/K} \tag{6}$$

where:

$$K = K_b + 1$$

The loss coefficient used in the program's orifice equation can be related to the loss coefficient C from another commonly used orifice flow equation, $Q = CA\sqrt{2gh}$. The conversion ($XKOR = 1/C^2$) can be used in utilizing tabulated values of C. However, care must be taken to insure the definition of h used in the various formulations is applicable.

The Bureau of Public Roads (reference j) shows experimental values for C for fully submerged conditions to vary from 0.7 to 0.9. A value of 0.8 is recommended as being applicable for the average two to four lane concrete girder bridge. The definition of h is consistent with that used in HEC-2. In the absence of calibration data, a value of 1.56 for XKOR (C = 0.8) would be applicable to most bridges and short culverts. For longer culverts, the coefficients given in Exhibit 2 of HEC-2 Users Manual can be used to compute XKOR as follows:

$$XKOR = k_e + k_f + 1$$

where:

k_e = entrance loss coefficient

k_f = friction loss coefficient

The coefficient for friction loss (k_f) can be computed from Manning's equation by equating two equations for friction loss in the culvert.

$$k_f \frac{V_b^2}{2g} = S_f \cdot L \qquad (7)$$

where:

S_f = the average friction slope

L = the length of the culvert

Manning's equation for the velocity in the culvert is rearranged to define S_f:

$$V_b = \frac{1.49}{n} R^{2/3} S_f^{1/2}$$

$$S_f = \frac{V_b^2 n^2}{2.22R^{4/3}} \qquad (8)$$

By substituting equation 8 for equation 7, the coefficient k_f can be defined based on culvert parameters.

$$k_f = \frac{V_b^2 n^2}{2.22R^{4/3}} \cdot L \cdot \frac{2g}{V_b^2}$$

$$k_f = 29n^2 L/R^{4/3} \qquad (9)$$

Typical values of the coefficients are shown below

Description	k
Intake	0.1 to 0.9
Intermediate piers	0.05
Friction (Mannings equation)	k_f

$$XKOR = \Sigma k + 1$$

where:

English $k_f = 29n^2 L/R^{4/3}$

Metric $k_f = 19.6n^2 L/R^{4/3}$

King's Handbook (reference e), in its discussion on pipe culverts, gives an entrance loss of .1 for a flush inlet, and 0.15 for a projecting inlet for concrete pipes. Inlet loss coefficients as high as 0.9 for a projecting entrance and corregated metal pipes are indicated. All the coefficients were applied to the velocity head for the pipe.

For Multiple Culverts, an equivalent coefficient can be computed to apply in cases where all culverts are flowing full.

$$Q = \sqrt{2gH}\ \ AT\ \sqrt{1/K_{equiv}}$$

where:

$$K_{equiv} = \frac{AT^2}{\left[\sum_{i=1}^{n} \sqrt{\frac{A_i^2}{K_i}}\right]^2}$$

AT = Total area

A_i = Area of individual culvert

K_i = Coefficient for individual culvert

n = number of culverts

Coefficient of Discharge, COFQ is used in the standard weir equation:

$$Q = CLH^{3/2}$$

Under free flow conditions (discharge independent of tailwater) the coefficient of discharge "C", ranges from 2.5 to 3.1 (1.39 - 1.72 metric) for broad-crested weirs depending primarily upon the gross head on the crest ("C" increases with head). Increased resistance to flow caused by obstructions such as trash on bridge railings, curbs, and other barriers

would decrease the value of C. With submerged flow (discharge affected by tailwater), the coefficient "C" should be reduced. This is done automatically by the program using the Waterways Experiment Station Design Chart 1114. The correction is based on model studies with a low ogee crest weir.

Tables of weir coefficients (C) are given for broad-crested weirs in King's Handbook with the value of C varying with measured head (H) and breadth of weir. For rectangular weirs with a breadth of 15 feet and a H of 1 foot or more the given value is 2.63. Trapezoidal shaped weirs generally have a larger coefficient with typical values ranging from 2.7 to 3.8.

Hydraulics of Bridge Waterways (reference j) provides a curve of C versus the head on the roadway. The roadway section is shown as a trapezoid and the coefficient rapidly changes from 2.9 for a very small H to 3.03 for H = 0.6 feet. From there, the curve levels off near a value 3.05.

With very little prototype data available, it seems the assumption of a rectangular weir for flow over the bridge deck (assuming the bridge can withstand the forces) and a coefficient of 2.6 would be reasonable. If the weir flow is over the roadway approaches to the bridge, a value of 3.0 would be consistent with available data. If weir flow occurs over a combination of bridge and roadway, an average coefficient (weighted by weir length) could be used.

EXAMPLES OF INPUT PREPARATION

Introduction

Example problems using the two bridge routines and the direct input of bridge loss are provided to illustrate input preparation. The special bridge routine is used for a "typical bridge with piers" and the normal bridge routine is used for a circular culvert. A simple example illustrates use of the X5 card to read in a change in water surface elevation. A separate section, Bridge Problems and Suggested Approaches, presents the modifications of basic input requirements for some typical bridge problems such as multiple bridge openings, perched bridges, low water bridges and others.

Special Bridge Routine Example

The example problem shown in Figure 8 is a bridge that spans the entire floodway and has abutments that constrict the natural flow. To simplify input, it will be assumed that the reach has a constant cross sectional shape and has a bed slope of zero. Other pertinent data is shown on the Figure. The following discussion describes the input problem and the input is shown in Figure 9. A computer run with the data set is given in Appendix I.

The problem is set up for a multiple profile run using the QT card. Manning's 'n' values are read on the NC card and contraction and expansion coefficients of 0.3 and 0.5 were selected.

Cross Section 1 is the downstream cross section located where the

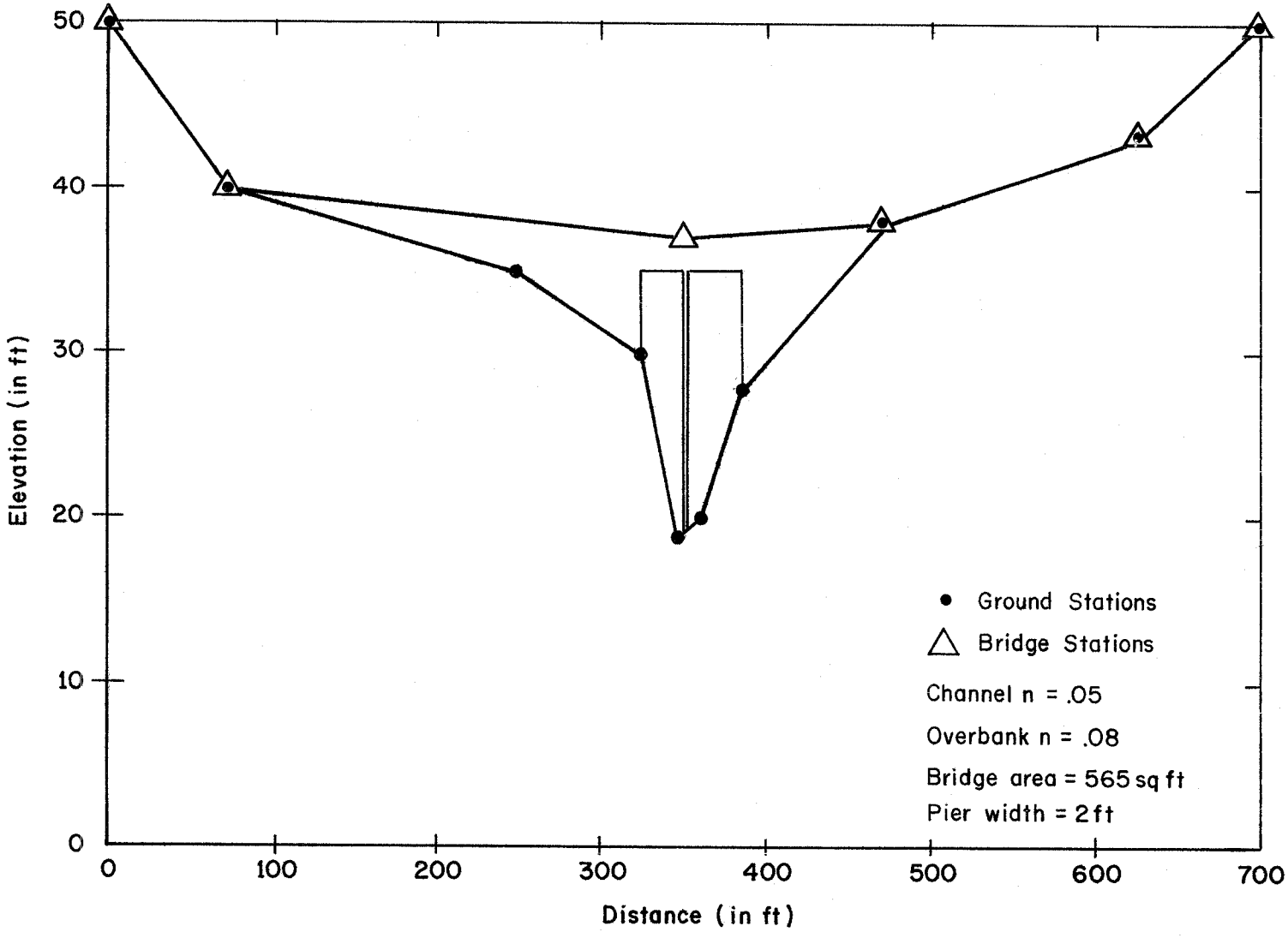


Figure 8. Special Bridge Routine Sample Section

GENERAL PURPOSE DATA FORM

(8 COLUMN FIELDS)

PROGRAM HEC-2 DATE

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	1	2	3	4	5	6	7	8	9	10
T1	SPECIAL BRIDGE ROUTINE EXAMPLE									
T2										
T3										
J1		2							30.0	
NC	.08	.08	.05	.3	.5					
QT	3	2000	4500	6000						
X1	1	10	325	375	0	0	0			
GR	50	0	40	75	35	250	30	325	19	345
GR	20	360	28	375	38	475	43	625	59	700
X1	2				300	300	300			
X3	10							36	36	
SB	1.05	1.6	2.6		15	2	565	1.6	20	20
X1	3				40	40	40			
X2			1	35	37					
X3	10							37	37	
BT	6	0	50		75	40		350	37	
BT	475	38		625	43		700	50		
X1	4				75	75	75			
EJ										
T1	SECOND PROFILE									
T2										
T3										
J1		3							34.0	
J2	2									
T1	THIRD PROFILE									
T2										
T3										
J1		4							36.0	
J2	15									

Figure 9. Special Bridge Example Input

flow has fully expanded beck onto the flood plain. The section will be repeated as cross section 2; therefore, the left and right bank stations are selected to be consistent with the bridge opening. The section is located downstream using the 4:1 expansion of the flow as previously presented. The reach lengths for the first section are set to zero as this is the section where the profile is being initiated. The GR cards are used to describe the natural ground section in the usual manner.

Cross section 2 is immediately downstream from the bridge. The reach lengths between sections 1 and 2 are set equal to 4 times the average abutment length (75 ft ±) for a total reach length of 300 ft. Because the natural section was considered applicable, the ground profile was repeated.

The effective area option is used at section 2 to confine the flow to the bridge opening when flow through the bridge is low flow or pressure flow. The left and right bank stations have already been set consistent with the abutment locations. All that is required is the X3 card with a 10 in the first field and the selection of an elevation above which weir flow can be expected over the bridge. For the initial data input, the elevation at cross section 2 corresponding to weir flow is generally unknown, so an estimate must be made. In the example, water cannot flow around the bridge so weir flow must pass over the bridge. A reasonable estimate for the downstream elevation (i.e. at cross section 2) is an elevation midway between the low chord and top of road elevations, or 36 feet in this example. The limiting elevations for the

effective area option are entered in fields 8 and 9 of the X3 card.

Card SB defines bridge characteristics for the special bridge routine. The first three variables are the coefficients for computing class A low flow, pressure flow, and weir flow respectively. The first field contains the pier shape coefficient for the Yarnell equation. The shape of the piers is the basis for selecting the coefficient as shown on page 30. For the example, twin-cylinder piers without diaphragm require a coefficient of 1.05. For a bridge without piers, the first field can be left blank.

For the pressure flow calculations, the value of XKOR is used in the orifice equation. Based on the typical value suggested by the Bureau of Public Roads, a value of 1.6 was selected.

The weir flow coefficient, COFQ, is used to calculate weir flow. In the example, most of the weir flow would occur over the bridge rather than the road, so a value of 2.6 was selected.

The variable RDLEN was not used because it is only applicable for a horizontal weir with a crest length RDLEN. To define the weir profile for the example problem the BT cards are used.

Six variables on the SB card provide the data to model the bridge opening. Five variables define the bridge for low flow calculations with the momentum and Yarnell equations. The bottom width of the trapezoid (BWC) and the side slopes (SS) provide the basic trapezoid. Variable BWP gives the total width of piers and ELCHU and ELCHD give the upstream and downstream elevations for the invert of the trapezoid. The sixth

variable, BAREA, provides the net area of the bridge opening for calculating pressure flow.

In making a trapezoidal approximation of a bridge opening, dimensions should be chosen so that the corresponding water surface elevation vs. area curve duplicates as closely as possible the elevation vs. area curve for the actual bridge opening. If the area-elevation relation cannot be preserved over the complete range of elevations, emphasis should be placed on the range of elevations to be used in the problem. If low flows are to be run, then the elevation-area curve corresponding to the trapezoid should be appropriate for the lower depths in the bridge section. For high flows, the small depths would not be as important. To check the trapezoidal area for large flows (where the opening is submerged), the program user should compute the net area of the bridge opening using the trapezoidal model and compare it to the net bridge area (BAREA) based on the actual bridge. The two areas should be close, especially if flows near the bridge's low flow capacity are being computed.

The variables ELCHU and ELCHD define the upstream and downstream invert elevations for the trapezoidal area. If the trapezoid invert is the same as the minimum elevation (ELMIN) for the previous cross section (section 2 in this example), then the elevations can be left blank on the SB card. In some cases, the invert elevation must be set higher than ELMIN to give a better bridge model (elevation-area curve) at higher discharges. In those cases, the invert elevations can be

read on the SB card.

For the example problem, the invert elevation for the trapezoid was set at 20 feet, slightly higher than the actual elevation. A bottom width of 15 feet and side slopes of 1.6 give a reasonable trapezoidal approximation. Total net area based on the trapezoidal model is 555 square feet.

The variable BAREA is the net area under the bridge to be used in the orifice equation. Once the program has determined that flow through the bridge is by pressure flow, the trapezoidal approximation is no longer used, and flow calculations are made using the orifice equation. The total open area under the bridge (BAREA) is used for the pressure flow calculations. Based on the given bridge geometry, an area of 565 square feet is entered in field 7 of the SB card.

Cross section 3, immediately upstream from the bridge, is a repeat of cross section 2 for this example. The reach lengths for this section are the length of the water course through the bridge.

Following the X1 card for section 3 is an X2 card. This card is required with the special bridge routine to call the special bridge routine (IBRID = 1 in field 3) and to give test elevations for pressure flow and weir flow (ELLC and ELTRD in fields 4 and 5). The maximum elevation on the low chord of the bridge, ELLC, is used by the program to check if there is a possibility of pressure flow. The low point of the top of road, ELTRD, is used to test if weir flow exists. Even though the program can scan the BT cards to find these elevations, it is good

practice to always specify them on the X2 card. Also, the need for low chord elevations on the BT cards is eliminated when coding a bridge with piers for the special bridge routine. The effective area option is defined for section 3 in the same manner as for section 2. For the upstream side of the bridge, the elevations for the control of effective area are set to the minimum top of road (ELTRD). As in section 2, the X3 card has a 10 in the first field and the control elevations in fields 8 and 9.

The BT cards, necessary to define the weir for the special bridge routine, are placed with input cards for section 3. Because the bridge in the example problem has piers, the program will remain with the special bridge routine for all solutions. That is, the program cannot revert to the normal bridge routine for the given input. This is important to check when coding the BT cards because it can simplify input. If the program remains in the special bridge routine, all that is needed on the BT cards is specification of road stations and elevations to define the weir. In defining the weir under these circumstances, road stations do not have to be consistent with the GR card stations.

Without a pier, the special bridge routine will use standard step calculations for low flow and for combination weir and low flow solutions (the weir equation would not be used). When standard step calculations are made, the program computes conveyance by segments across the section; therefore, the BT stations under these conditions would have to line up with GR stations and both top of road and low chord elevations

would have to be given. The BT cards in the example show the minimum required data for the example problem.

Section 3 is a repeat section, so there are no GR cards. If GR cards were used with section 3, they would follow the BT cards.

Cross section 4 completes the model for the example problem. It is a full flow section located upstream from the bridge beyond the zone of flow contraction. The reach length is estimated by a one to one ratio of the average abutment constriction on the flow. In the example, the distance is 75 feet. Because the same ground geometry is used, no GR cards are read.

If the contraction and expansion coefficients, read on card NC, were to be changed to lower values for subsequent profile calculations proceeding upstream from cross section 4, the new values would be read in after section 4 and before the next X1 card.

The coded input for this problem was run on HEC-2. The program output is shown in Appendix I.

Normal Bridge Routine Example

The second example, a circular culvert, will be modeled using the normal bridge routine. Again, the problem is fairly simple and intended to illustrate the basic input requirements. The geometric data are shown in Figure 10 and the completed coding form is shown in Figure 11. The computer solution for the problem is shown in Appendix II. Discussion of the input follows.

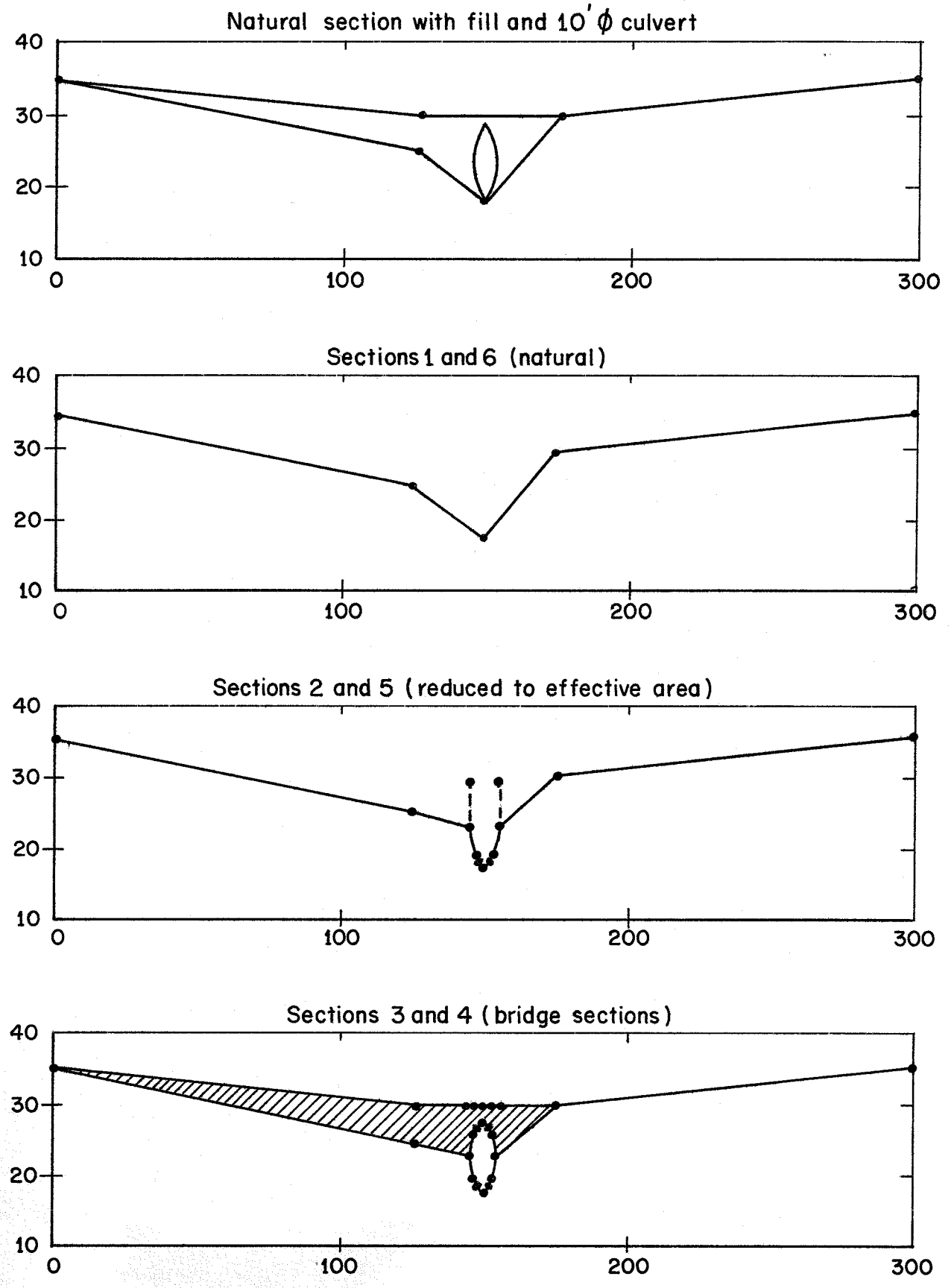

Figure 10. Normal Bridge Routine Section

GENERAL PURPOSE DATA FORM

(8 COLUMN FIELDS)

PROGRAM HEC-2 DATE

REQUESTED BY BONNER PREPARED BY CHECKED BY PAGE / OF /

	1	2	3	4	5	6	7	8	9	10
T1	NORMAL BRIDGE ROUTINE EXAMPLE									
T2	CIRCULAR CULVERT									
T3										
J1								450	25	
NC	.08	.08	.03	.3	.5					
X1	1	5	125	175	0	0	0			
GR	35	0	25	125	19	150	30	175	35	300
X1	2	11	145	155	100	100	100			
X3	10							29	29	
GR	35	0	25	125	23	145	19.5	145.5	18.5	147.5
GR	18	150	18.5	152.5	19.5	154.5	23	155	30	175
GR	35	300								
NC			.012							
X1	3				10	10	10			
RT	11	0	35	35	125	30	25	145	30	23
BT	145.5	30	25.5	147.5	30	27.5	150	30	28	152.5
BT	30	27.5	154.5	30	25.5	155	30	23	175	30
BT	30	300	35							
X1	4				100	100	100			
X2							1			
NC			.03							
X1	5				10	10	10			
X3	10							30	30	
X1	6	5	125	175	25	25	25			
GR	35	0	25	125	19	150	30	175	35	300
EJ										

Figure 11. Normal Bridge Example Input

A single profile is to be calculated with Manning's 'n' values defined on the NC card. The starting n values define the natural channel and overbanks. Contraction and expansion coefficients of 0.3 and 0.5 respectively were selected.

The first two cross sections represent the same modeling situation discussed under the special bridge routine example. Cross Section 1 is the downstream section located where the flow has fully expanded onto the flood plain. It is located 100 feet downstream from the bridge based on the 4:1 expansion of the flow as previously presented. Cross Section 2 is just downstream from the bridge and represents the contracted effective flow leaving the culvert. The X3 card is used, as before, to call the effective area option and to extend the elevation of channel control for cases where all the flow is going through the culvert.

Input for the normal bridge routine differs from input for the special bridge at this point. After cross section 2 located immediately downstream from the bridge, comes cross section 3 representing a section through the bridge. For the culvert the Manning's 'n' value for the channel should change. Therefore, the NC card is read in prior to cross section 3 with a channel 'n' value of 0.012 for the culvert.

After changing the 'n' value for the culvert, the culvert is described using the X1 and GR cards to describe the lower half of the culvert and the BT cards to describe the top half. Because the main chan-

nel for section 2 is defined as the lower half of the culvert, section 3 is read in as a repeat section. To model the culvert, BT cards are added to section 3 to complete the top half of the culvert.

The BT cards for the normal bridge routine should only have stations that are used on the GR cards. Consistent stationing is required because the program computes the conveyance of the cross section incrementally for each GR station. To properly correct the area and wetted perimeter for the presence of the bridge, the given BT stations must coincide with the GR stations. For GR stations between given BT stations, the program will linearly interpolate the road elevation (variable RDEL) and low chord elevation (variable XCEL) to calculate the incremental conveyance.

For bridge stations in the overbank areas, the low chord elevation (XCEL) is usually set equal to the ground point elevation (EL on the GR card). In the channel area, the low chord elevation defines the low chord of the bridge. For the example problem, the low chord elevations define the top half of the culvert. The top of road elevations define the road profile for the cross section.

As Cross Section 3 is just inside the culvert on the downstream side, Cross Section 4 is located inside the culvert at the upstream end. This section is a repeat section of the downstream culvert section. The cross section elevations were not changed; however, the culvert can be modeled with a slope by adding an incremental elevation in field 9 of the X1 card. The BT cards for this section are also repeated from section 3 by using the X2 card with a 1 in field 7 (variable REPBT).

If the culvert had been modeled with a slope, the same incremental elevation adjustment used on the X1 card would be applied by the program to the low chord elevations on the BT card. The top of road elevations are not changed by the program. The standard step solution from section 3 to section 4 determines friction and expansion or contraction losses through the culvert. If only friction losses should be computed, the values for the contraction and expansion coefficients should be redefined to very small values just before section 4. After section 4, the values can be reset to calculate shock losses.

Cross Section 5 represents the effective flow area just upstream from the bridge. The Manning's 'n' value must first be changed back to represent the channel. An NC card with the channel 'n' value is read in just before cross section 5. The section is modeled as a repeat of the cross section 4, but without the BT cards. The effective area option is again used to maintain the flow in the channel up to the top of road elevation (X3 card with 10 in field 1 and control elevations in fields 8 and 9).

The last cross section for the bridge model is a section upstream from the zone of contraction for the bridge. Cross Section 6 represents the full flood plain and is located 25 feet upstream determined by using a one on one contraction rate. The ground section is redefined by GR cards. This cross section completes the geometric model for the Normal Bridge routine.

Input Bridge Loss Example

Bridge losses can be read into the program by two different methods. A bridge loss in terms of a change in water surface elevation can be read on the X2 card (variable BLOSS on field 6) or on the X5 card. The X5 card will be demonstrated in this example because it can be used for multiple profiles, where as only a single loss can be read on the X2 card.

The example used with the special bridge routine will be repeated here. However, instead of modeling the bridge, the calculation will involve only cross sections 1 and 4 (see fig. 8 on page 37) and the bridge loss will be input at cross section 4. It is assumed for the application that the bridge loss has been determined externally from the program.

The input is a repeat of that for the previous Special Bridge Example (Figure 8 and 9) up through the first cross section. This is followed by input for the far upstream cross section 4. An X5 card is added to the usual data at section 4.

The X5 card can be used in two ways. Either a water surface elevation or a change in water surface can be defined. The choice is indicated on the card by the sign used (plus or minus) with the variable N on the first field. The variable indicates the number of values to be specified on the X5 card. A postive N indicates water surface elevations and a negative N indicates increments of water surface elevation. The latter is used in this example.

GENERAL PURPOSE DATA FORM

(8 COLUMN FIELDS)

PROGRAM HEC-2 DATE

REQUESTED BY BONNER PREPARED BY CHECKED BY PAGE 1 OF 1

	1	2	3	4	5	6	7	8	9	10
T1	BRIDGE PROBLEM WITH INPUT LOSS									
T2	XS CARD USED									
T3	WSEL CHANGE FROM SPECIAL BRIDGE PROBLEM									
J1		2							30	
NC	.08	.08	.05	.3	.5					
PT	3	2000	4500	6000						
X1	1	10	325	375	0	0	0			
GR	50	0	40	75	35	250	30	325	19	345
GR	20	360	28	375	38	475	43	625	50	700
X1	4				415	415	415			
XS	-3	1.07	2.20	2.56						
EJ										
T1	SECOND PROFILE									
T2										
T3										
J1		3							34	
J2	2									
T1	THIRD PROFILE									
T2										
T3										
J1		4							36	
J2	15									

Figure 12. Example Input of Direct Input for Bridge Loss

On multiple profile runs, the variable INQ (Field 2 of the J1 card) tells the program which field of the QT card to read. The same procedure is used to read the X5 card. In this example, each field to be read on the QT card has a corresponding bridge loss to be read on the X5 card. The first field of the X5 card shows the number of values to be read. The value in the first field is negative to indicate that changes in water surface elevation are to be read. The changes in the example are the computed results from the special bridge example. The computer run is shown in Appendix III.

BRIDGE PROBLEMS AND SUGGESTED APPROACHES

The examples presented in the previous section were for relatively simple structures so that fundamental principles of input preparation could be emphasized. However, many bridges are more complex than the one illustrated, and the following discussion is intended to show how HEC-2 can be used to calculate profiles for some of the types of bridges that are frequently encountered. The discussion here will be an extension of the previous examples and will address only those aspects of input preparation that have not been discussed previously.

Multiple Bridge Opening

Many bridges have more than one opening for flood flow, especially over very wide flood plains. Multiple culverts, bridges with side relief openings, and separate bridges over a divided channel are all examples of multiple bridge openings. With more than one bridge opening, and possibly different control elevations, the problem can be very complicated. Some general considerations follow.

For low flow situations, the normal bridge routine is more applicable than the special bridge routine. The SB card cannot be used to model more than one trapezoidal bridge opening. Modeling two or more separate bridge openings as one trapezoidal section with wide piers (variable BWP) is generally unsatisfactory because the semi-empirical Yarnell equation has not been calibrated for such flow conditions.

Pressure flow can be modeled with the special bridge routine, however, only one controlling elevation (ELLC) can be used. Therefore, if the maximum low chord elevation (variable ELLC) is the same on all bridge openings, or if the flow is high enough to inundate all the openings, the orifice equation can be used. The section on Loss Coefficients provides a method of computing an equivalent coefficient for multiple culverts.

If flow through some of the culverts is low flow while flow through other culverts is pressure flow, the program can not provide a direct solution with the special bridge routine. To use the special bridge routine, the openings would have to be modeled separately and a, "divided flow" approach would be required. (See Chow's "Open Channel Hydraulics," section on Flow Passing Islands, reference k.) A normal bridge solution could be directly obtained if the distribution of flow based on conveyance was reasonable and if one water surface elevation could be assumed for the entire bridge section.

Computer determination of low flow by the normal bridge routine and pressure flow by the special bridge routine can be obtained in a multiple profile run. By coding the bridge input using the special bridge routine but without a pier, the program will use the normal bridge routine for low flow solutions. The BT cards would have to be coded consistent with requirements for the normal bridge routine. For the higher discharges where pressure flow occurs, the solution would be obtained from the orifice equation in the special bridge routine.

Dams and Weirs

Flow over uncontrolled dams and weirs can be modeled with the special bridge routine. Weir flow is calculated over weirs defined by either the stations and road elevations on BT cards or by a fixed weir length (RDLEN) and elevation (ELTRD) defined on cards SB and X2 respectively. To use the special bridge routine where all flow is weir flow requires the same basic data as for a bridge. Recalling the calculation sequence, the special bridge routine assumes low flow and then pressure flow prior to determining that weir flow exists. On the SB card, it is necessary to input some arbitrarily small values for the variables defining the trapezoid and the orifice area (variables BWC, BAREA, and SS). The small areas defined by the trapezoid and BAREA will cause the program to solve for a combination of pressure flow and weir flow. With a very small orifice area, the pressure flow will be negligible and a weir flow solution will have been achieved.

Perched Bridges

A perched bridge is one for which the road approaching the bridge is at the flood plain ground level, and only in the immediate area of the bridge does the road rise above ground level to span the watercourse. A typical flood flow situation with this type of bridge is to have low flow under the bridge and overbank flow around the bridge. Because the road approaching the bridge is usually not much higher than the surrounding ground, the assumption of weir flow is often not justified. A solution

based on standard step calculations would be better than a solution based on weir flow with correction for submergence. Therefore, this type of bridge should generally be modeled using the normal bridge routine, especially when a large percentage of the total discharge is in the overbank areas.

Low Water Bridges

A low water bridge is designed to carry only low flows under the bridge. Flood flows are carried over the bridge and road. When modeling this bridge for flood flows, the anticipated solution is a combination of pressure and weir flow, which implies using the special bridge routine. However, with most of the flow over the top of the bridge, the correction for submergence may introduce considerable error. If the tailwater is going to be high, it may be better to use the normal bridge routine. In fact, if almost all the water is over the top, the bridge may be modeled as a cross section over the top of the bridge, ignoring the flow under the bridge.

Bridges on a Skew

Skewed bridge crossings are generally handled by making adjustments to the bridge dimensions to define an equivalent cross section perpendicular to the flow lines. The adjustments can be made in the normal bridge routine by multiplying the actual dimensions of the bridge by the cosine of the skew angle. The cosine of the angle is coded on the X1 card

(variable PXSECR in field 8) for the cross section coordinates on GR cards and on the X2 card (variable BSQ on field 9) for the data on the BT cards. If the special bridge routine is used, the data coded on the SB card must be adjusted prior to input. There is no internal method in the program to adjust the data on the SB card.

In the publication "Hydraulics of Bridge Waterways" (reference j) the effect of skew on low flow is discussed. In model testing, skewed crossings with angles up to 20° showed no objectionable flow patterns. For increasing angles, flow efficiency decreased. A graph illustrating the impact of skewness indicates that using the projected length is adequate for angles up to 30° for small flow contractions.

Parallel Bridges

With the construction of divided highways, a common modeling problem involves parallel bridges. For new highways, these bridges are often identical structures. The hydraulic losses through the two structures has been shown to be between one and two times the loss for one bridge (reference j). The model results shown in reference j indicate the loss for two bridges ranging from 1.3 to 1.55 times the loss for one bridge crossing, over the range of bridge spacings tested. Presumably if the two bridges were far enough apart, the losses for the two bridges would equal twice the loss for one. For the program user faced with a dual bridge problem, computing a single bridge loss and then adjusting it with criteria from reference j may be the most expedient approach.

If both bridges are modeled, care should be exercised in depicting the expansion of flow between the bridges.

REFERENCES

a. "Backwater Curves in River Channels," Engineering Manual 1110-2-1409, U.S. Army Corps of Engineers, 7 December 1959.

b. "Computer Determination of Flow Through Bridges," Eichert, B. S. and Peters, J.C., ASCE, J. Hyd. Div., Vol. 96, No. HY7, July 1970.

c. Koch-Carstanjen, "Von der Bewegung des Wassers und Den Dabei Auftretenden Kraften, Hydrofynamim," Berlin 1926. A partial translation appears in Appendix I, "Report on Engineering Aspects of Flood of March 1938," U.S. Angeineer Office, Los Angeles, May 1939.

d. "Handbook of Concrete Culvert Pipe Hydraulics," Portland Cement Association, 1964.

e. "Handbook of Hydraulics," Horace W. King and Ernest F. Brater, Fifth Edition, McGraw - Hill Book Company, 1963.

f. "HEC-2, Water Surface Profiles," Users Manual, The Hydrologic Engineering Center, November 1976.

g. "HEC-2, Water Surface Profiles," Programmers Manual, The Hydrologic Engineering Center, November 1976.

h. "Hydraulic Design of Reservoir Outlet Structures," Engineering Manual 1110-2-1602, U.S. Army Engineers, 1 August 1963.

i. "Hydraulic Design of Spillways," Engineering Manual 1110-2-1603, U.S. Army Corps of Engineers, 31 March 1965, Plate 33.

j. "Hydraulics of Bridge Waterways," Hydraulic Branch, Bridge Division, Office Engineering and Operations, Bureau of Public Roads, 1970.

k. "Open Channel Hydraluics," Ven Te Chow, McGraw - Hill Book Company, 1959.

l. "Water Surface Profiles," IHD Volume 6, The Hydrologic Engineering Center, July 1975.

Appendix I

SPECIAL BRIDGE EXAMPLE

COMPUTER RUN

THIS RUN EXECUTED 6 JAN 81 16:40:34

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**************************************************
  HEC2 RELEASE DATED NOV 76 UPDATED APRI 1980
  ERROR CORR -  01,02,03,04
  MODIFICATION -  50,51,52,53,54
**************************************************

T1      SPECIAL BRIDGE METHOD EXAMPLE
T2      LOW FLOW PROFILE
T3

J1  ICHECK    INQ       NINV      IDIR      STRT      METRIC    HVINS     Q         WSEL      FQ

       0.        2.        0.        0.  0.000000      0.00      0.0       0.    30.000     0.000

J3  VARIABLE CODES FOR SUMMARY PRINTOUT

    100.000   105.000     0.000     0.000     0.000     0.000     0.000     0.000     0.000     0.000

NC      0.080     0.080     0.050     0.300     0.500     0.000     0.000     0.000     0.000     0.000
QT      3.000  2000.000  4500.000  6000.000     0.000     0.000     0.000     0.000     0.000     0.000

X1      1.000    10.000   325.000   375.000     0.000     0.000     0.000     0.000     0.000     0.000
GR     50.000     0.000    40.000    75.000    35.000   250.000    30.000   325.000    19.000   345.000
GR     20.000   360.000    28.000   375.000    38.000   475.000    43.000   625.000    50.000   700.000

X1      2.000     0.000     0.000     0.000   240.000  2340.000   240.000     0.000     0.000     0.000
X3     10.000     0.000     0.000     0.000     0.000     0.000     0.000    36.000    36.000     0.000
SB      1.050     1.600     2.600     0.000    15.000     2.000   565.000     1.600    20.000    20.000

X1      3.000     0.000     0.000     0.000    40.000    40.000    40.000     0.000     0.000     0.000
X2      0.000     0.000     1.000    35.000    37.000     0.000     0.000     0.000     0.000     0.000
X3     10.000     0.000     0.000     0.000     0.000     0.000     0.000    37.000    37.000     0.000
BT      6.000     0.000    50.000     0.000    75.000    40.000     0.000   350.000    37.000     0.000
BT    475.000    38.000     0.000   625.000    43.000     0.000   700.000    50.000     0.000     0.000

X1      4.000     0.000     0.000     0.000    60.000    60.000    60.000     0.000     0.000     0.000
EJ      0.000     0.000     0.000     0.000     0.000     0.000     0.000     0.000     0.000     0.000
```

```
   SECNO     DEPTH     CWSEL     CRIWS     WSELK     EG        HV        HL        OLOSS    BANK ELEV
   Q         QLOB      QCH       QROB      ALOB      ACH       AROB      VOL       TWA    LEFT/RIGHT
   TIME      VLOB      VCH       VROB      XNL       XNCH      XNR       WTN       ELMIN       SSTA
   SLOPE     XLOBL     XLCH      XLOBR     ITRIAL    IDC       ICONT     CORAR     TOPWID      ENDST


*PROF 1

CCHV=   0.300 CEHV=   0.500
*SECNO 1.000
     1.00     11.00     30.00      0.00     30.00     30.47      0.47      0.00      0.00     30.00
    2000.       0.      1980.      20.        0.       358.      20.        0.        0.      28.00
     0.00      0.00      5.54      0.99      0.080     0.050     0.080     0.000     19.00    325.00
 0.002853        0.        0.        0.         0         0         0      0.00     70.00    395.00

*SECNO 2.000

3495 OVERBANK AREA ASSUMED NON-EFFECTIVE,ELLEA=       36.00 ELREA=       36.00

     2.00     11.70     30.70      0.00      0.00     31.11      0.40      0.61      0.02     30.00
    2000.       0.      2000.        0.        0.      393.       0.        3.        1.      28.00
     0.01      0.00      5.09      0.00      0.080     0.050     0.080     0.048     19.00    325.00
 0.002125      240.      240.     2340.         2         0         0      0.00     50.00    375.00


SPECIAL BRIDGE

SB  XK         XKOR       COFQ       RDLEN      BWC        BWP        BAREA      SS         ELCHU      ELCHD
     1.05       1.60       2.60       0.00      15.00       2.00     565.00       1.60      20.00      20.00

*SECNO 3.000
CLASS A LOW FLOW

3420 BRIDGE W.S.=     30.61 BRIDGE VELOCITY=,      6.29      CALCULATED CHANNEL AREA=,      318.

 EGPRS      EGLWC       H3        QWEIR      QPR        BAREA    TRAPEZOID      ELLC       ELTRD
                                                                    AREA
     0.00      31.15       0.04         0.      2000.       565.      555.       35.00      37.00


3495 OVERBANK AREA ASSUMED NON-EFFECTIVE,ELLEA=       37.00 ELREA=       37.00

     3.00     11.75     30.75      0.00      0.00     31.15      0.40      0.04      0.00     30.00
    2000.       0.      2000.        0.        0.      395.       0.        3.        1.      28.00
     0.02      0.00      5.07      0.00      0.080     0.050     0.080     0.048     19.00    325.00
 0.002090       40.       40.       40.         0         0         0      0.00     50.00    375.00
```

SECNO	DEPTH	CWSEL	CRIWS	WSELK	EG	HV	HL	OLOSS	BANK ELEV
Q	QLOB	QCH	QROB	ALOB	ACH	AROB	VOL	TWA	LEFT/RIGHT
TIME	VLOB	VCH	VROB	XNL	XNCH	XNR	WTN	ELMIN	SSTA
SLOPE	XLOBL	XLCH	XLOBR	ITRIAL	IDC	ICONT	CORAR	TOPWID	ENDST
*SECNO 4.000									
4.00	11.92	30.92	0.00	0.00	31.28	0.36	0.12	0.01	30.00
2000.	3.	1953.	44.	6.	404.	43.	4.	1.	28.00
0.02	0.48	4.84	1.03	0.080	0.050	0.080	0.048	19.00	311.19
0.001854	60.	60.	60.	2	0	0	0.00	93.02	404.21

THIS RUN EXECUTED 6 JAN 81 16:40:37

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**************************************************
  HEC2 RELEASE DATED NOV 76 UPDATED APRI 1980
  ERROR CORR -  01,02,03,04
  MODIFICATION -  50,51,52,53,54
**************************************************

T1      PRESSIRE FLOW PROFILE
T2
T3
```

J1	ICHECK	INQ	NINV	IDIR	STRT	METRIC	HVINS	Q	WSEL	FQ
	0.	3.	0.	0.	0.000000	0.00	0.0	0.	34.000	0.000

J2	NPROF	IPLOT	PRFVS	XSECV	XSECH	FN	ALLDC	IBW	CHNIM	ITRACE
	2.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

```
   SECNO     DEPTH     CWSEL     CRIWS     WSELK     EG        HV        HL        OLOSS    BANK ELEV
   Q         QLOB      QCH       QROB      ALOB      ACH       AROB      VOL       TWA    LEFT/RIGHT
   TIME      VLOB      VCH       VROB      XNL       XNCH      XNR       WTN       ELMIN       SSTA
   SLOPE     XLOBL     XLCH      XLOBR     ITRIAL    IDC       ICONT     CORAR     TOPWID      ENDST

*PROF 2

CCHV=   0.300 CEHV=   0.500
*SECNO 1.000
     1.00     15.00     34.00      0.00     34.00     34.70      0.70      0.00      0.00     30.00
    4500.      180.     3966.      354.      120.      558.      180.        0.        0.     28.00
     0.00      1.50      7.11      1.96     0.080     0.050     0.080     0.000     19.00    265.00
 0.002603        0.        0.        0.         0         0         0      0.00    170.00    435.00

*SECNO 2.000

3495 OVERBANK AREA ASSUMED NON-EFFECTIVE,ELLEA=       36.00 ELREA=       36.00

     2.00     15.76     34.76      0.00      0.00     35.65      0.89      0.85      0.09     30.00
    4500.        0.     4500.        0.        0.      595.        0.        8.        2.     28.00
     0.01      0.00      7.56      0.00     0.080     0.050     0.080     0.037     19.00    325.00
 0.002690       240.      240.     2340.         4         0         0      0.00     50.00    375.00

SPECIAL BRIDGE

SB  XK        XKOR      COFQ      RDLEN     BWC       BWP       BAREA     SS        ELCHU     ELCHD
     1.05      1.60      2.60      0.00     15.00      2.00    565.00      1.60     20.00     20.00

*SECNO 3.000
PRESSURE FLOW

 EGPRS      EGLWC       H3       QWEIR      QPR       BAREA   TRAPEZOID      ELLC      ELTRD
                                                              AREA
    36.34     35.73      0.10         0.     4500.      565.      555.      35.00     37.00


3495 OVERBANK AREA ASSUMED NON-EFFECTIVE,ELLEA=       37.00 ELREA=       37.00

     3.00     16.56     35.56      0.00      0.00     36.34      0.78      0.69      0.00     30.00
    4500.        0.     4500.        0.        0.      636.        0.        9.        2.     28.00
     0.01      0.00      7.08      0.00     0.080     0.050     0.080     0.038     19.00    325.00
 0.002165        40.       40.       40.         2         0         0      0.00     50.00    375.00
```

SECNO	DEPTH	CWSEL	CRIWS	WSELK	EG	HV	HL	OLOSS	BANK ELEV
Q	QLOB	QCH	QROB	ALOB	ACH	AROB	VOL	TWA	LEFT/RIGHT
TIME	VLOB	VCH	VROB	XNL	XNCH	XNR	WTN	ELMIN	SSTA
SLOPE	XLOBL	XLCH	XLOBR	ITRIAL	IDC	ICONT	CORAR	TOPWID	ENDST

*SECNO 4.000

4.00	17.21	36.21	0.00	0.00	36.56	0.35	0.09	0.13	30.00
4500.	427.	3534.	538.	304.	668.	337.	10.	2.	28.00
0.02	1.41	5.29	1.60	0.080	0.050	0.080	0.040	19.00	207.65
0.001131	60.	60.	60.	2	0	0	0.00	249.45	457.10

THIS RUN EXECUTED 6 JAN 81 16:40:38

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**************************************************
  HEC2 RELEASE DATED NOV 76 UPDATED APRI 1980
  ERROR CORR -  01,02,03,04
  MODIFICATION -  50,51,52,53,54
**************************************************
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T1 PRESSURE AND WEIR FLOW PROFILE
T2
T3

J1	ICHECK	INQ	NINV	IDIR	STRT	METRIC	HVINS	Q	WSEL	FQ
	0.	4.	0.	0.	0.000000	0.00	0.0	0.	36.000	0.000

J2	NPROF	IPLOT	PRFVS	XSECV	XSECH	FN	ALLDC	IBW	CHNIM	ITRACE
	15.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

SECNO	DEPTH	CWSEL	CRIWS	WSELK	EG	HV	HL	OLOSS	BANK ELEV
Q	QLOB	QCH	QROB	ALOB	ACH	AROB	VOL	TWA	LEFT/RIGHT
TIME	VLOB	VCH	VROB	XNL	XNCH	XNR	WTN	ELMIN	SSTA
SLOPE	XLOBL	XLCH	XLOBR	ITRIAL	IDC	ICONT	CORAR	TOPWID	ENDST

*PROF 3

CCHV= 0.300 CEHV= 0.500

*SECNO 1.000

1.00	17.00	36.00	0.00	36.00	36.66	0.66	0.00	0.00	30.00
6000.	533.	4771.	696.	280.	658.	320.	0.	0.	28.00
0.00	1.90	7.26	2.17	0.080	0.050	0.080	0.000	19.00	215.00
0.002173	0.	0.	0.	0	0	0	0.00	240.00	455.00

*SECNO 2.000

2.00	18.14	37.14	0.00	0.00	37.60	0.46	0.88	0.06	30.00
6000.	741.	4451.	808.	430.	715.	419.	26.	6.	28.00
0.03	1.73	6.23	1.93	0.080	0.050	0.080	0.024	19.00	174.75
0.001430	240.	240.	2340.	2	0	0	0.00	291.75	466.50

SPECIAL BRIDGE

SB	XK	XKOR	COFQ	RDLEN	BWC	BWP	BAREA	SS	ELCHU	ELCHD
	1.05	1.60	2.60	0.00	15.00	2.00	565.00	1.60	20.00	20.00

*SECNO 3.000

PRESSURE AND WEIR FLOW

EGPRS	EGLWC	H3	QWEIR	QPR	BAREA	TRAPEZOID AREA	ELLC	ELTRD
39.94	37.64	0.03	1084.	4867.	565.	555.	35.00	37.00

3.00	19.71	38.71	0.00	0.00	38.99	0.28	1.38	0.00	30.00
6000.	1029.	4003.	969.	707.	793.	579.	27.	6.	28.00
0.03	1.46	5.05	1.67	0.080	0.050	0.080	0.026	19.00	120.14
0.000819	40.	40.	40.	2	0	2	0.00	376.16	496.30

*SECNO 4.000

4.00	19.77	38.77	0.00	0.00	39.04	0.27	0.05	0.00	30.00
6000.	1040.	3985.	976.	719.	796.	586.	30.	6.	28.00
0.03	1.45	5.01	1.66	0.080	0.050	0.080	0.028	19.00	118.00
0.000801	60.	60.	60.	1	0	0	0.00	380.15	498.14

```
**************************************************
  HEC2 RELEASE DATED NOV 76 UPDATED APRI 1980
  ERROR CORR -  01,02,03,04
  MODIFICATION -  50,51,52,53,54
**************************************************

NOTE- ASTERISK (*) AT LEFT OF CROSS-SECTION NUMBER INDICATES MESSAGE IN SUMMARY OF ERRORS LIST
```

SUMMARY PRINTOUT TABLE 100

SECNO	EGLWC	ELLC	EGPRS	ELTRD	QPR	QWEIR	CLASS	H3	DEPTH	CWSEL	VCH	EG
3.000	31.15	35.00	0.00	37.00	2000.00	0.00	1.00	0.04	11.75	30.75	5.07	31.15
3.000	35.73	35.00	36.34	37.00	4500.00	0.00	10.00	0.10	16.56	35.56	7.08	36.34
3.000	37.64	35.00	39.94	37.00	4867.18	1083.85	30.00	0.03	19.71	38.71	5.05	38.99

SUMMARY PRINTOUT TABLE 105

SECNO	CWSEL	HL	OLOSS	TOPWID	QLOB	QCH	QROB
1.000	30.00	0.00	0.00	70.00	0.00	1980.22	19.78
1.000	34.00	0.00	0.00	170.00	180.25	3966.11	353.64
1.000	36.00	0.00	0.00	240.00	532.78	4771.26	695.96
2.000	30.70	0.61	0.02	50.00	0.00	2000.00	0.00
2.000	34.76	0.85	0.09	50.00	0.00	4500.00	0.00
2.000	37.14	0.88	0.06	291.75	741.16	4451.08	807.76
3.000	30.75	0.04	0.00	50.00	0.00	2000.00	0.00
3.000	35.56	0.69	0.00	50.00	0.00	4500.00	0.00
3.000	38.71	1.38	0.00	376.16	1028.61	4002.80	968.59
4.000	30.92	0.12	0.01	93.02	3.03	1953.21	43.76
4.000	36.21	0.09	0.13	249.45	427.46	3534.50	538.05
4.000	38.77	0.05	0.00	380.15	1039.59	3984.71	975.71

Appendix II

NORMAL BRIDGE EXAMPLE

COMPUTER RUN

```
**************************************************
  HEC2 RELEASE DATED NOV 76 UPDATED APRI 1980
  ERROR CORR -  01,02,03,04
  MODIFICATION -  50,51,52,53,54
**************************************************


T1      NORMAL BRIDGE METHOD
T2      10 FOOT CIRCULAR CULVERT
T3

J1  ICHECK    INQ       NINV      IDIR      STRT      METRIC    HVINS     Q         WSEL      FQ

       0.        0.        0.        0.  0.000000      0.00      0.0     450.    25.000     0.000

NC      0.080     0.080     0.030     0.300     0.500     0.000     0.000     0.000     0.000     0.000


X1      1.000     5.000   125.000   175.000     0.000     0.000     0.000     0.000     0.000     0.000
GR     35.000     0.000    25.000   125.000    18.000   150.000    30.000   175.000    35.000   300.000


X1      2.000    11.000   145.000   155.000   100.000   100.000   100.000     0.000     0.000     0.000
X3     10.000     0.000     0.000     0.000     0.000     0.000     0.000    29.000    29.000     0.000
GR     35.000     0.000    25.000   125.000    23.000   145.000    19.500   145.500    18.500   147.500
GR     18.000   150.000    18.500   152.500    19.500   154.500    23.000   155.000    30.000   175.000
GR     35.000   300.000     0.000     0.000     0.000     0.000     0.000     0.000     0.000     0.000
NC      0.000     0.000     0.012     0.000     0.000     0.000     0.000     0.000     0.000     0.000


X1      3.000     0.000     0.000     0.000    10.000    10.000    10.000     0.000     0.000     0.000
BT     11.000     0.000    35.000    35.000   125.000    30.000    25.000   145.000    30.000    23.000
BT    145.500    30.000    25.500   147.500    30.000    27.500   150.000    30.000    28.000   152.500
BT     30.000    27.500   154.500    30.000    25.500   155.000    30.000    23.000   175.000    30.000
BT     30.000   300.000    35.000     0.000     0.000     0.000     0.000     0.000     0.000     0.000


X1      4.000     0.000     0.000     0.000   100.000   100.000   100.000     0.000     0.000     0.000
X2      0.000     0.000     0.000     0.000     0.000     0.000     1.000     0.000     0.000     0.000
NC      0.000     0.000     0.030     0.000     0.000     0.000     0.000     0.000     0.000     0.000


X1      5.000     0.000     0.000     0.000    10.000    10.000    10.000     0.000     0.000     0.000
X3     10.000     0.000     0.000     0.000     0.000     0.000     0.000    30.000    30.000     0.000
```

```
X1      6.000      5.000    125.000    175.000     25.000     25.000     25.000      0.000      0.000      0.000
GR     35.000      0.000     25.000    125.000     18.000    150.000     30.000    175.000     35.000    300.000
EJ      0.000      0.000      0.000      0.000      0.000      0.000      0.000      0.000      0.000      0.000
```



```
   SECNO     DEPTH     CWSEL     CRIWS     WSELK     EG        HV        HL        OLOSS    BANK ELEV
   Q         QLOB      QCH       QROB      ALOB      ACH       AROB      VOL       TWA    LEFT/RIGHT
   TIME      VLOB      VCH       VROB      XNL       XNCH      XNR       WTN       ELMIN       SSTA
   SLOPE     XLOBL     XLCH      XLOBR     ITRIAL    IDC       ICONT     CORAR     TOPWID      ENDST

*PROF 1

CCHV=   0.300 CEHV=   0.500
*SECNO 1.000
     1.00      7.00     25.00      0.00     25.00     25.16      0.16      0.00      0.00     25.00
     450.       0.      450.        0.       0.       139.       0.        0.        0.       30.00
     0.00      0.00      3.25      0.00     0.080     0.030     0.080     0.000     18.00    125.00
 0.000879       0.        0.        0.       0         0         0       0.00      39.58    164.58

*SECNO 2.000

3301 HV CHANGED MORE THAN HVINS


3495 OVERBANK AREA ASSUMED NON-EFFECTIVE,ELLEA=       29.00 ELREA=       29.00

     2.00      6.80     24.80      0.00      0.00     25.69      0.89      0.17      0.36     23.00
     450.       0.      450.        0.       0.       60.        0.        0.        0.       23.00
     0.00      0.00      7.55      0.00     0.080     0.030     0.080     0.030     18.00    145.00
 0.004249      100.      100.      100.       2         0         0       0.00      10.00    155.00

*SECNO 3.000

3370 NORMAL BRIDGE,NRD= 11 MIN ELTRD=   30.00 MAX ELLC=   35.00

     3.00      6.81     24.81     22.81      0.00     25.72      0.90      0.02      0.01     23.00
     450.       0.      450.        0.       0.       59.        0.        0.        0.       23.00
     0.00      0.00      7.62      0.00     0.080     0.012     0.080     0.028     18.00    126.77
 0.000915       10.       10.       10.       2        18         0     -22.03     33.44    160.21
```

*SECNO 4.000

3370 NORMAL BRIDGE,NRD= 11 MIN ELTRD= 30.00 MAX ELLC= 35.00

4.00	6.95	24.95	22.81	0.00	25.82	0.87	0.09	0.01	23.00
450.	0.	450.	0.	0.	60.	0.	0.	0.	23.00
0.01	0.00	7.47	0.00	0.080	0.012	0.080	0.020	18.00	125.50
0.000871	100.	100.	100.	4	18	0	-25.20	35.07	160.57

SECNO	DEPTH	CWSEL	CRIWS	WSELK	EG	HV	HL	OLOSS	BANK ELEV
Q	QLOB	QCH	QROB	ALOB	ACH	AROB	VOL	TWA	LEFT/RIGHT
TIME	VLOB	VCH	VROB	XNL	XNCH	XNR	WTN	ELMIN	SSTA
SLOPE	XLOBL	XLCH	XLOBR	ITRIAL	IDC	ICONT	CORAR	TOPWID	ENDST

*SECNO 5.000

3495 OVERBANK AREA ASSUMED NON-EFFECTIVE,ELLEA= 30.00 ELREA= 30.00

5.00	7.02	25.02	0.00	0.00	25.84	0.83	0.02	0.01	23.00
450.	0.	450.	0.	0.	62.	0.	0.	0.	23.00
0.01	0.00	7.30	0.00	0.080	0.030	0.080	0.021	18.00	145.00
0.003785	10.	10.	10.	2	0	0	0.00	10.00	155.00

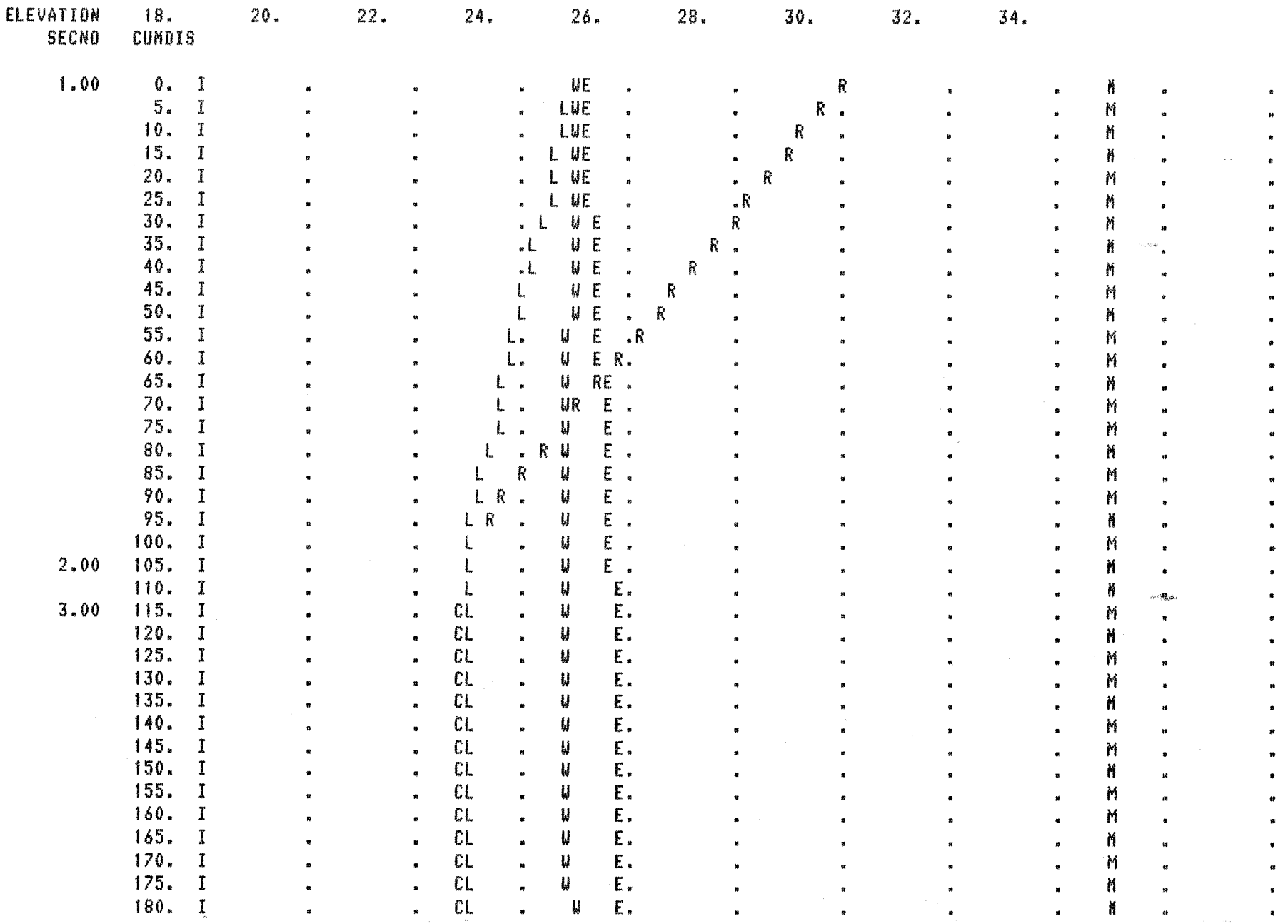
*SECNO 6.000

3301 HV CHANGED MORE THAN HVINS

6.00	7.99	25.99	0.00	0.00	26.08	0.10	0.02	0.22	25.00
450.	1.	449.	0.	6.	179.	0.	0.	0.	30.00
0.01	0.23	2.51	0.00	0.080	0.030	0.080	0.021	18.00	112.66
0.000402	25.	25.	25.	3	0	0	0.00	53.98	166.64

PROFILE FOR STREAM

PLOTTED POINTS (BY PRIORITY)-E-ENERGY,W-WATER SURFACE,I-INVERT,C-CRITICAL W.S.,L-LEFT BANK,R-RIGHT BANK,M-LOWER END STA



```
        185.  I        .        .  CL    .    W   E.        .        .        .        .  M    .        .
        190.  I        .        .  CL    .    W   E.        .        .        .        .  M    .        .
        195.  I        .        .  CL    .    W   E.        .        .        .        .  M    .        .
        200.  I        .        .  CL    .    W   E.        .        .        .        .  M    .        .
        205.  I        .        .  CL    .    W   E.        .        .        .        .  M    .        .
        210.  I        .        .  CL    .    W   E.        .        .        .        .  M    .        .
4.00    215.  I        .        .  CL    .    W   E.        .        .        .        .  M    .        .
        220.  I        .        .   L    .    W   E.        .        .        .        .  M    .        .
5.00    225.  I        .        .   L    .    W   E.        .        .        .        .  M    .        .
        230.  I        .        .     L  . R   W  E.        .        .        .        .  M    .        .
        235.  I        .        .       L.      W RE        .        .        .        .  M    .        .
        240.  I        .        .        .L      W E     R  .        .        .        .  M    .        .
        245.  I        .        .        .  L     WE        .  R     .        .        .  M    .        .
6.00    250.  I        .        .        .    L    E        .        R        .        .  M    .        .
```

6 JAN 81 16:34:34 PAGE 4

Appendix III

INPUT LOSS EXAMPLE

COMPUTER RUN

THIS RUN EXECUTED 6 JAN 81 15:24:25

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**************************************************
  HEC2 RELEASE DATED NOV 76 UPDATED APRI 1980
  ERROR CORR -  01,02,03,04
  MODIFICATION -  50,51,52,53,54
**************************************************

T1      BRIDGE PROBLEM WITH INPUT LOSS
T2           X5 CARD USED
T3      WSEL CHANGE FROM SPECIAL BRIDGE PROBLEM

J1  ICHECK    INQ       NINV      IDIR      STRT      METRIC    HVINS     Q         WSEL      FQ

       0.       2.        0.        0.  0.000000      0.00      0.0       0.    30.000    0.000

NC     0.080     0.080     0.050     0.300     0.500     0.000     0.000     0.000     0.000     0.000
QT     3.000  2000.000  4500.000  6000.000     0.000     0.000     0.000     0.000     0.000     0.000

X1     1.000    10.000   325.000   375.000     0.000     0.000     0.000     0.000     0.000     0.000
GR    50.000     0.000    40.000    75.000    35.000   250.000    30.000   325.000    19.000   345.000
GR    20.000   360.000    28.000   375.000    38.000   475.000    43.000   625.000    50.000   700.000

X1     4.000     0.000     0.000     0.000   415.000   415.000   415.000     0.000     0.000     0.000
X5    -3.000     1.075     2.560     0.000     0.000     0.000     0.000     0.000     0.000     0.000
EJ     0.000     0.000     0.000     0.000     0.000     0.000     0.000     0.000     0.000     0.000
```

SECNO	DEPTH	CWSEL	CRIWS	WSELK	EG	HV	HL	OLOSS	BANK ELEV
Q	QLOB	QCH	QROB	ALOB	ACH	AROB	VOL	TWA	LEFT/RIGHT
TIME	VLOB	VCH	VROB	XNL	XNCH	XNR	WTN	ELMIN	SSTA
SLOPE	XLOBL	XLCH	XLOBR	ITRIAL	IDC	ICONT	CORAR	TOPWID	ENDST

*PROF 1

CCHV= 0.300 CEHV= 0.500

*SECNO 1.000

1.00	11.00	30.00	0.00	30.00	30.47	0.47	0.00	0.00	30.00
2000.	0.	1980.	20.	0.	358.	20.	0.	0.	28.00
0.00	0.00	5.54	0.99	0.080	0.050	0.080	0.000	19.00	325.00
0.002853	0.	0.	0.	0	0	0	0.00	70.00	395.00

*SECNO 4.000

WATER EL=X5 CARD= 31.075

4.00	12.07	31.08	0.00	0.00	31.41	0.34	0.91	0.04	30.00
2000.	4.	1947.	48.	9.	411.	47.	4.	1.	28.00
0.02	0.51	4.73	1.03	0.080	0.050	0.080	0.050	19.00	308.87
0.001730	415.	415.	415.	0	0	0	0.00	96.87	405.75

```
**************************************************
  HEC2 RELEASE DATED NOV 76 UPDATED APRI 1980
  ERROR CORR -  01,02,03,04
  MODIFICATION -  50,51,52,53,54
**************************************************

T1      SECOND PROFILE
T2
T3

J1  ICHECK    INQ       NINV      IDIR      STRT      METRIC    HVINS     Q         WSEL      FQ

       0.       3.        0.        0.  0.000000      0.00      0.0       0.    34.000     0.000

J2  NPROF     IPLOT     PRFVS     XSECV     XSECH     FN        ALLDC     IBW       CHNIM     ITRACE

     2.000     0.000     0.000     0.000     0.000     0.000     0.000     0.000     0.000     0.000
```



```
   SECNO     DEPTH     CWSEL     CRIWS     WSELK     EG        HV        HL        QLOSS    BANK ELEV
   Q         QLOB      QCH       QROB      ALOB      ACH       AROB      VOL       TWA    LEFT/RIGHT
   TIME      VLOB      VCH       VROB      XNL       XNCH      XNR       WTN       ELMIN       SSTA
   SLOPE     XLOBL     XLCH      XLOBR     ITRIAL    IDC       ICONT     CORAR     TOPWID      ENDST

*PROF 2

CCHV=   0.300 CEHV=   0.500
*SECNO 1.000
     1.00     15.00     34.00      0.00     34.00     34.70      0.70      0.00      0.00     30.00
    4500.      180.     3966.      354.      120.      558.      180.        0.        0.     28.00
     0.00      1.50      7.11      1.96     0.080     0.050     0.080     0.000     19.00    265.00
 0.002603        0.        0.        0.         0         0         0      0.00    170.00    435.00

*SECNO 4.000
 WATER EL=X5 CARD=    36.560
     4.00     17.56     36.56      0.00      0.00     36.87      0.31      0.63      0.12     30.00
    4500.      475.     3461.      564.      347.      685.      366.       11.        2.     28.00
     0.03      1.37      5.05      1.54     0.080     0.050     0.080     0.050     19.00    195.40
 0.000995      415.      415.      415.         0         0         0      0.00    265.20    460.60
```

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**************************************************
  HEC2 RELEASE DATED NOV 76 UPDATED APRI 1980
  ERROR CORR -  01,02,03,04
  MODIFICATION -  50,51,52,53,54
**************************************************

T1      THIRD PROFILE
T2
T3

J1  ICHECK    INQ       NINV      IDIR      STRT      METRIC    HVINS     Q         WSEL      FQ

       0.       4.        0.        0.  0.000000      0.00      0.0       0.    36.000     0.000

J2  NPROF     IPLOT     PRFVS     XSECV     XSECH     FN        ALLDC     IBW       CHNIM     ITRACE

    15.000     0.000     0.000     0.000     0.000     0.000     0.000     0.000     0.000     0.000
```



```
   SECNO     DEPTH     CWSEL     CRIWS     WSELK     EG        HV        HL        OLOSS    BANK ELEV
   Q         QLOB      QCH       QROB      ALOB      ACH       AROB      VOL       TWA    LEFT/RIGHT
   TIME      VLOB      VCH       VROB      XNL       XNCH      XNR       WTN       ELMIN       SSTA
   SLOPE     XLOBL     XLCH      XLOBR     ITRIAL    IDC       ICONT     CORAR     TOPWID      ENDST

*PROF 3

CCHV=   0.300 CEHV=   0.500
*SECNO 1.000
     1.00     17.00     36.00      0.00     36.00     36.66      0.66      0.00      0.00     30.00
    6000.      533.     4771.      696.      280.      658.      320.        0.        0.     28.00
     0.00      1.90      7.26      2.17     0.080     0.050     0.080     0.000     19.00    215.00
 0.002173        0.        0.        0.         0         0         0      0.00    240.00    455.00

*SECNO 4.000
     4.00     17.98     36.98      0.00      0.00     37.47      0.49      0.75      0.05     30.00
    6000.      710.     4498.      792.      405.      707.      403.        13.       2.     28.00
     0.02      1.75      6.37      1.96     0.080     0.050     0.080     0.050     19.00    180.70
 0.001520      415.      415.      415.         2         0         0      0.00    284.11    464.80
```

THIS RUN EXECUTED 6 JAN 81 15:24:34

****
HEC2 RELEASE DATED NOV 76 UPDATED APRI 1980
ERROR CORR - 01,02,03,04
MODIFICATION - 50,51,52,53,54
****

NOTE- ASTERISK (*) AT LEFT OF CROSS-SECTION NUMBER INDICATES MESSAGE IN SUMMARY OF ERRORS LIST

WSEL CHANGE FROM SPECIAL

SUMMARY PRINTOUT TABLE 150

SECNO	XLCH	ELTRD	ELLC	ELMIN	Q	CWSEL	CRIWS	E6	10K*S	VCH	AREA	.01K
1.000	0.00	0.00	0.00	19.00	2000.00	30.00	0.00	30.47	28.53	5.54	377.50	374.42
1.000	0.00	0.00	0.00	19.00	4500.00	34.00	0.00	34.70	26.03	7.11	857.50	882.08
1.000	0.00	0.00	0.00	19.00	6000.00	36.00	0.00	36.66	21.73	7.26	1257.50	1287.06
4.000	415.00	0.00	0.00	19.00	2000.00	31.08	0.00	31.41	17.30	4.73	467.20	480.91
4.000	415.00	0.00	0.00	19.00	4500.00	36.56	0.00	36.87	9.95	5.05	1398.96	1426.40
4.000	415.00	0.00	0.00	19.00	6000.00	36.98	0.00	37.47	15.20	6.37	1514.34	1538.97

SECNO	Q	CWSEL	DIFWSP	DIFWSX	DIFKWS	TOPWID	XLCH
1.000	2000.00	30.00	0.00	0.00	0.00	70.00	0.00
1.000	4500.00	34.00	4.00	0.00	0.00	170.00	0.00
1.000	6000.00	36.00	2.00	0.00	0.00	240.00	0.00
4.000	2000.00	31.08	0.00	1.07	0.00	96.87	415.00
4.000	4500.00	36.56	5.48	2.56	0.00	265.20	415.00
4.000	6000.00	36.98	0.42	0.98	0.00	284.11	415.00

SUMMARY OF ERRORS

NOTE SECNO= 4.000 PROFILE= 1 WSEL BASED ON X5 CARD
NOTE SECNO= 4.000 PROFILE= 2 WSEL BASED ON X5 CARD